Research on Liquefaction Modeling in Deep Deposits

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MECHANICS OF LIQUEFACTION

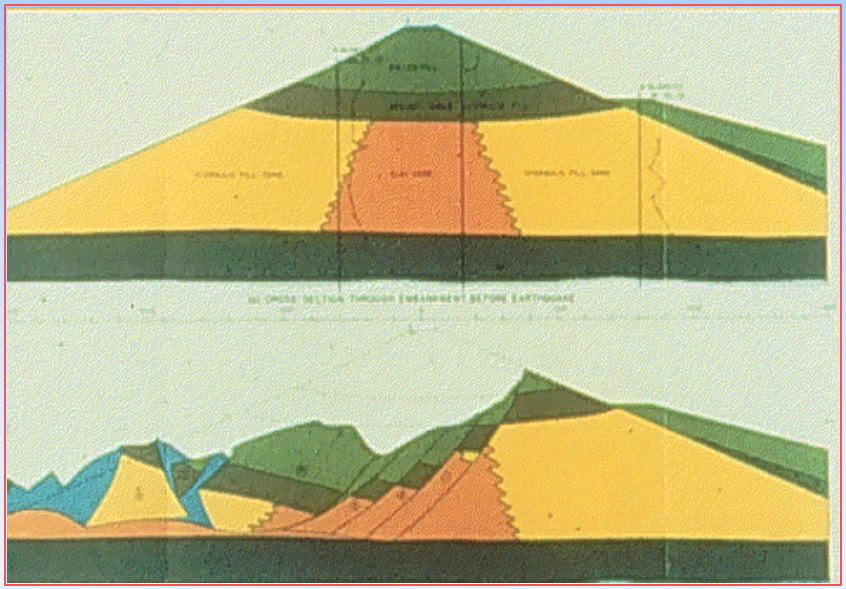
- **Influence of depth (effective confining stress)**
- **Applied shear stress**
- **Coupling effects (solid-water, normal-shear)**

Lower San Fernando Dam

- **Role of time scales (dissipation versus wave propagation)**
- **Determination of properties (property versus element test)**
- **System Response**

KEY RESEARCH QUESTIONS

- *Do centrifuge experiments give reasonable results?*
- *Does numerical model give reasonable results?*
- *Can physical mechanisms be identified?*
- *To what extent can results be generalized?*



Lower San Fernando Dam

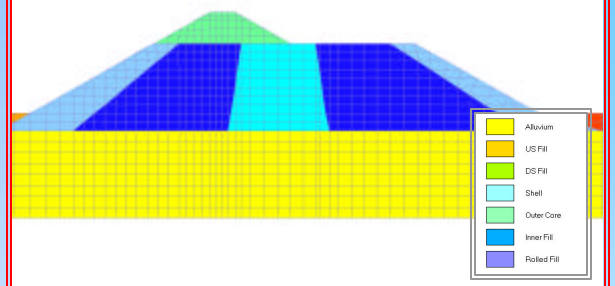
OUTLINE OF PRESENTATION

- *Description of STUBBS model*
- *Response of an element*
- *Analysis of a deep versus shallow sand layer*
- *Comments on element versus layer response*
- *Conclusions*

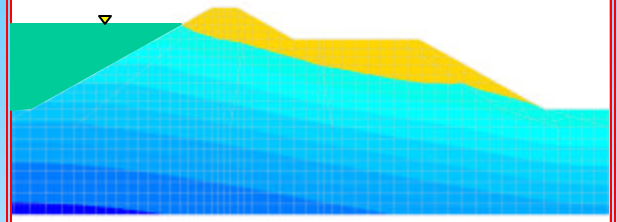
Lower San Fernando Dam

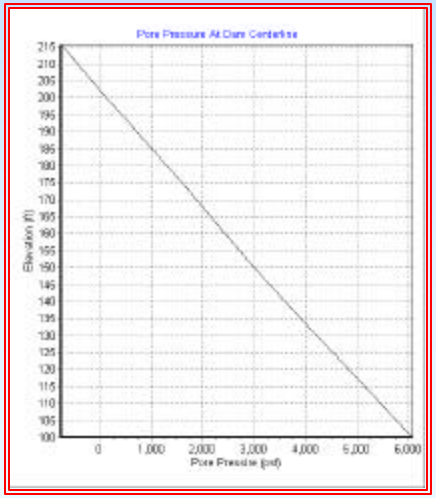
STUBBS: Comprehensive Analysis Package for Geotechnical Engineering

Materials Distribution



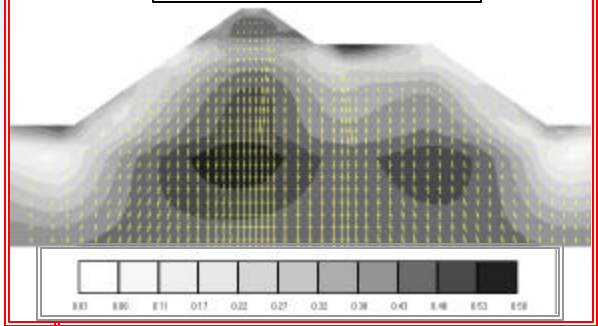
Pore Pressure Distribution





- Construction Simulation
- Seepage
- Stability Analysis
- Consolidation
- Dynamic Analysis

Stress Distribution

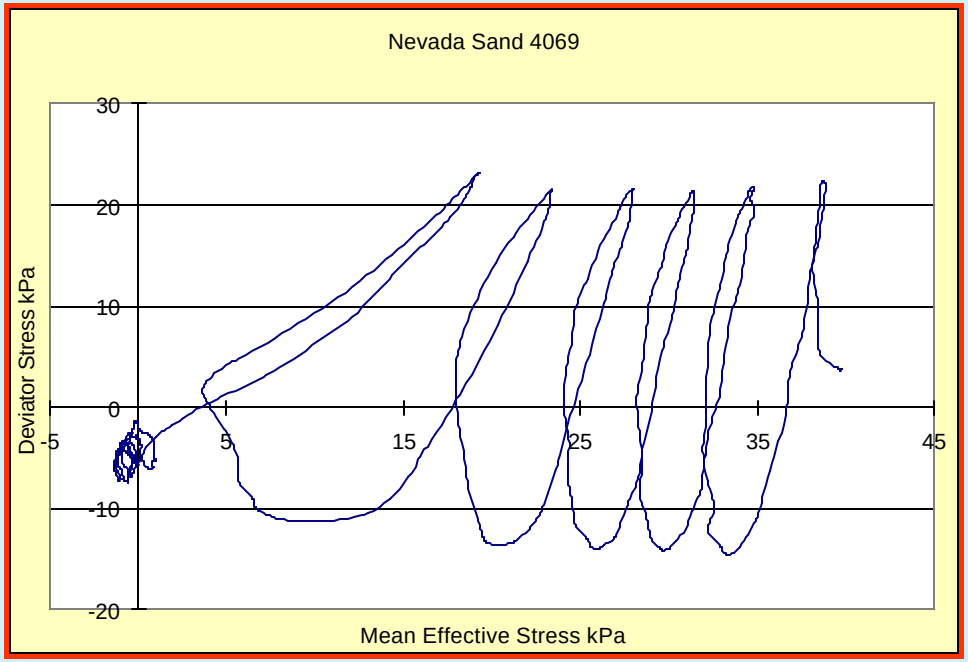


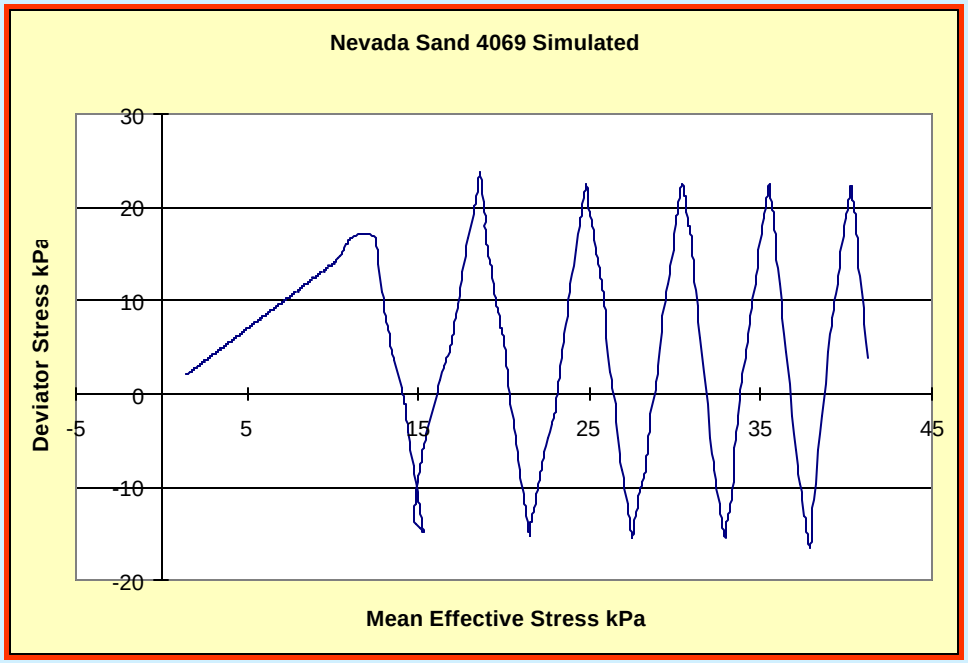
Element Response

Constitutive Model

Key Behavior Modes:

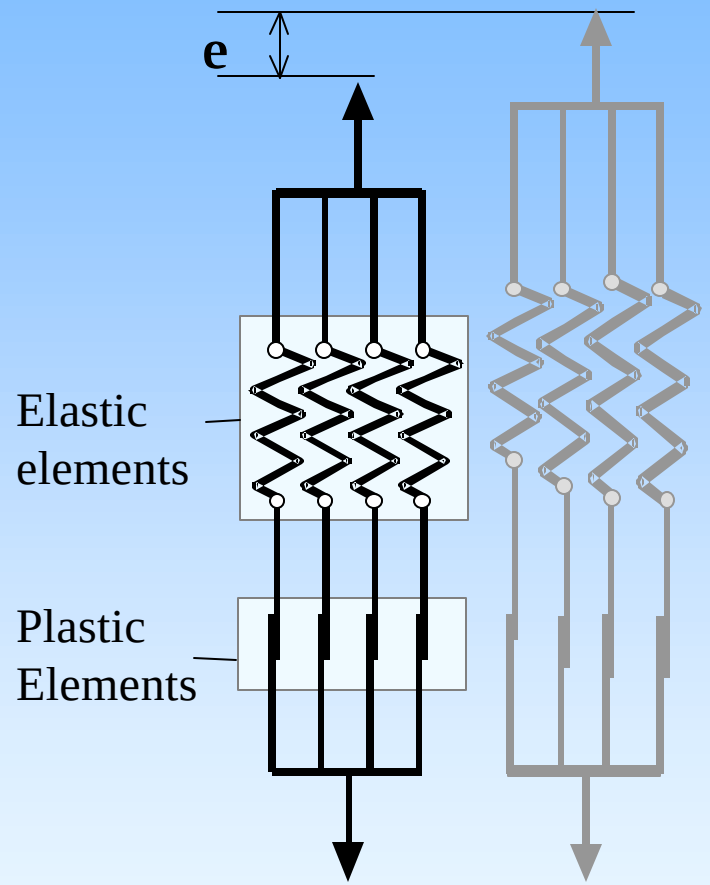
- *Drained Monotonic Loading*
- **Undrained Monotonic**
- **Loading**
- **Drained Cyclic**
- *Undrained Cyclic*





Multi-Mechanical Concept

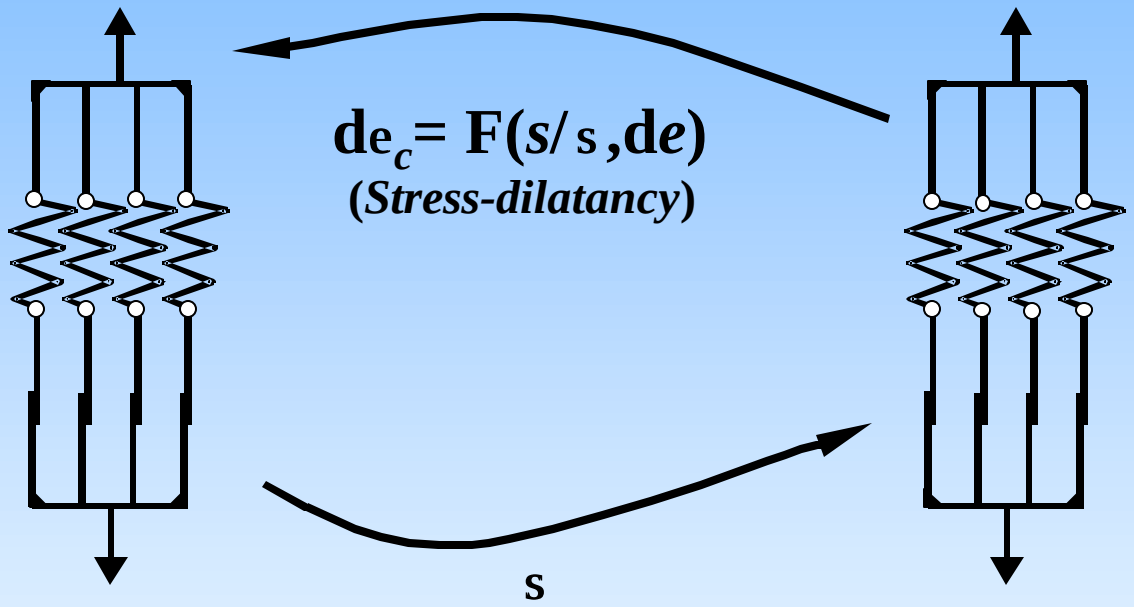
- **Mechanistic interpretation to *endochronic* model used in earlier versions of STUBBS**
- **Simple implementation and calibration**
- **Captures history effects**
- **Consistent with traditional *critical state* concepts**
- **Based on effective stress**



Parallel array of elastic and plastic elements

Shear-Volume Coupling

$de_H = de - de_c$



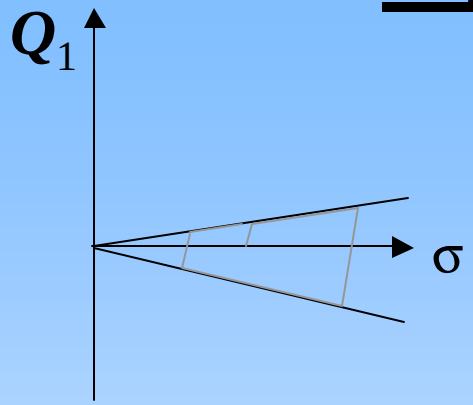
Volumetric

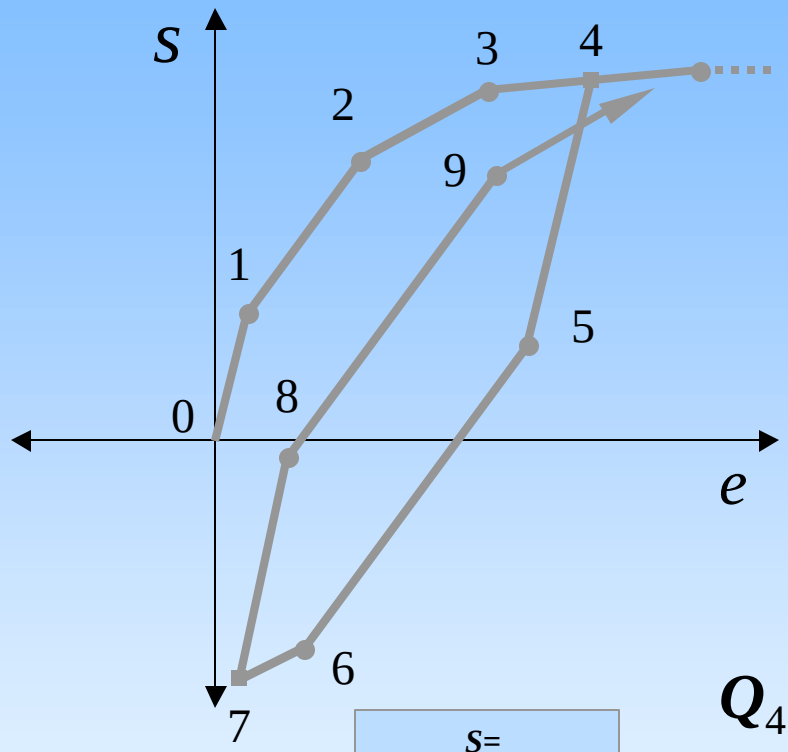
$s - e_H$

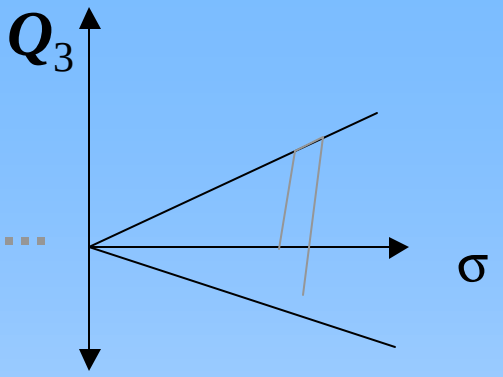
Shear

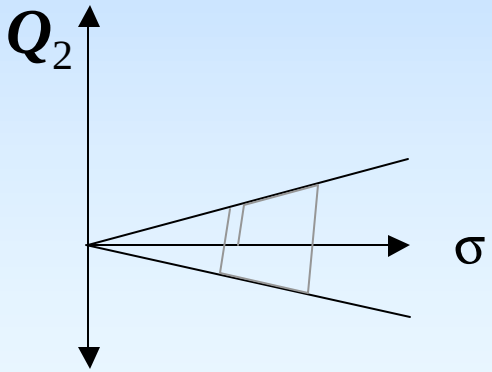
s-e

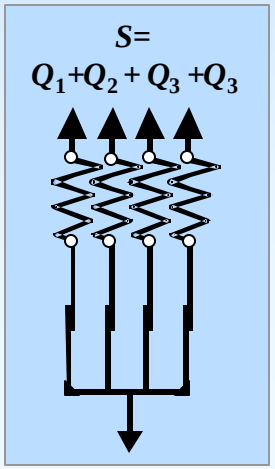
History Effects from State Dependence

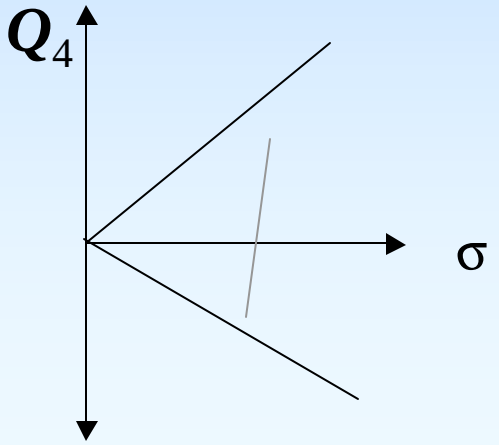


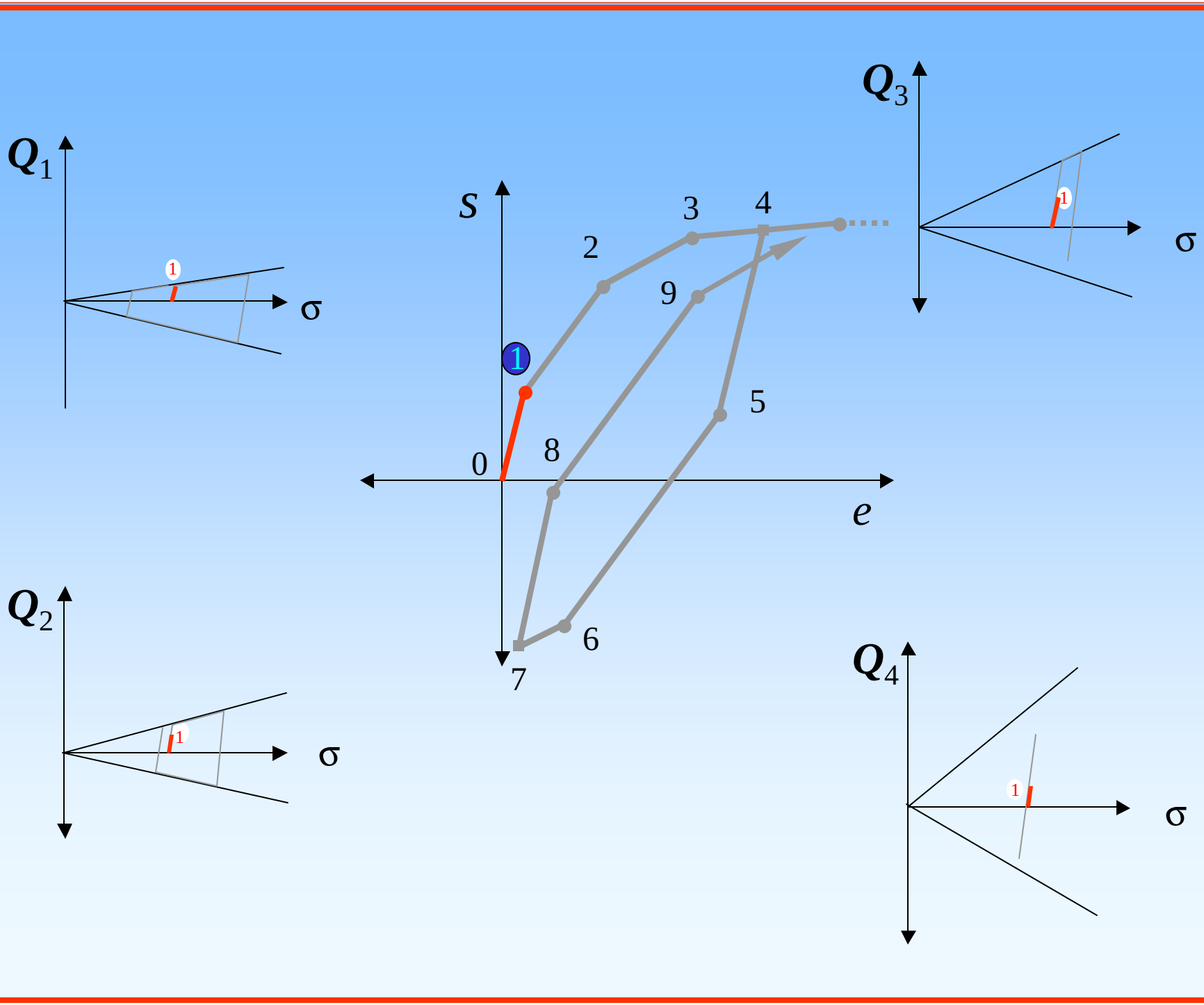








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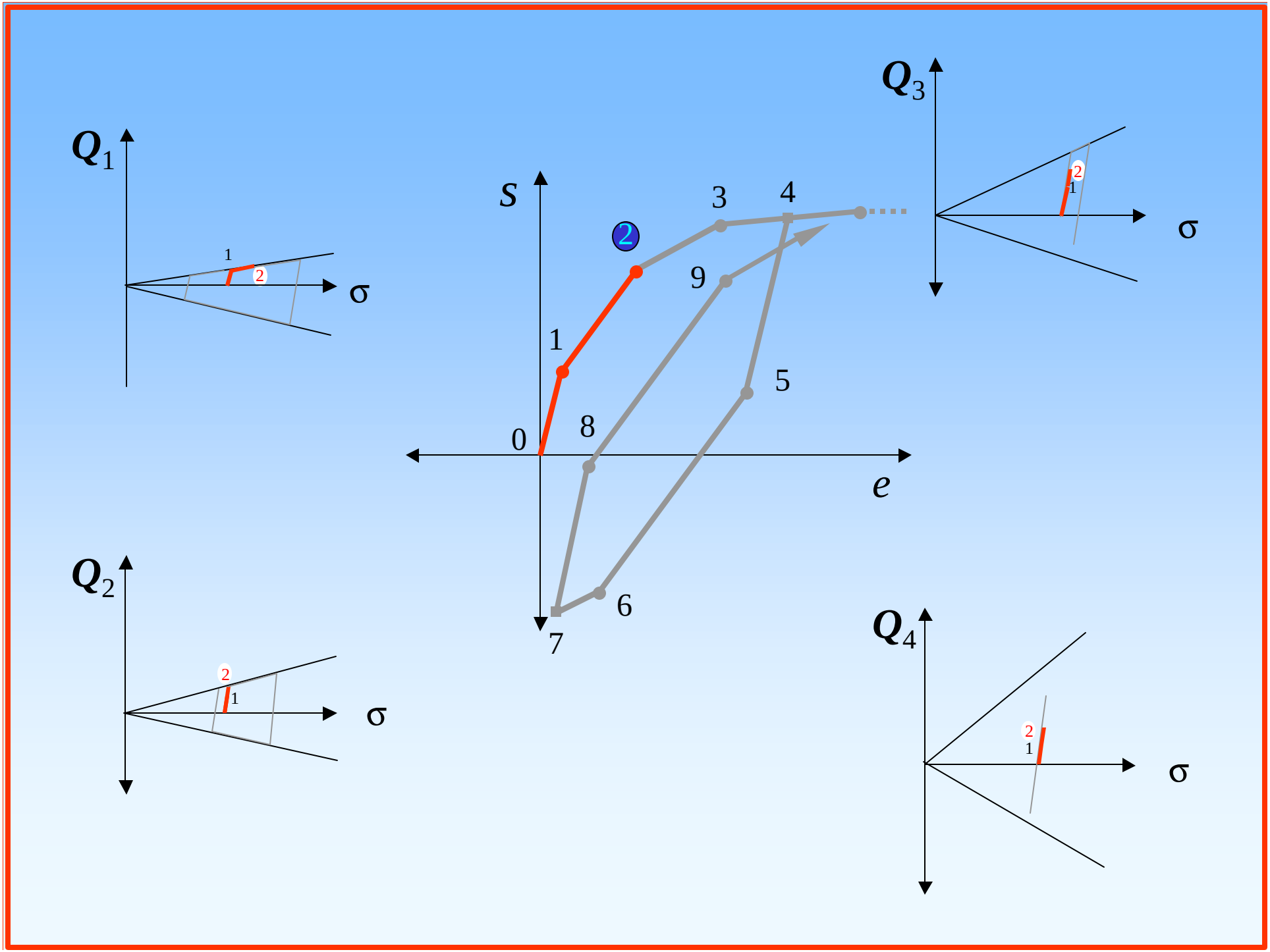
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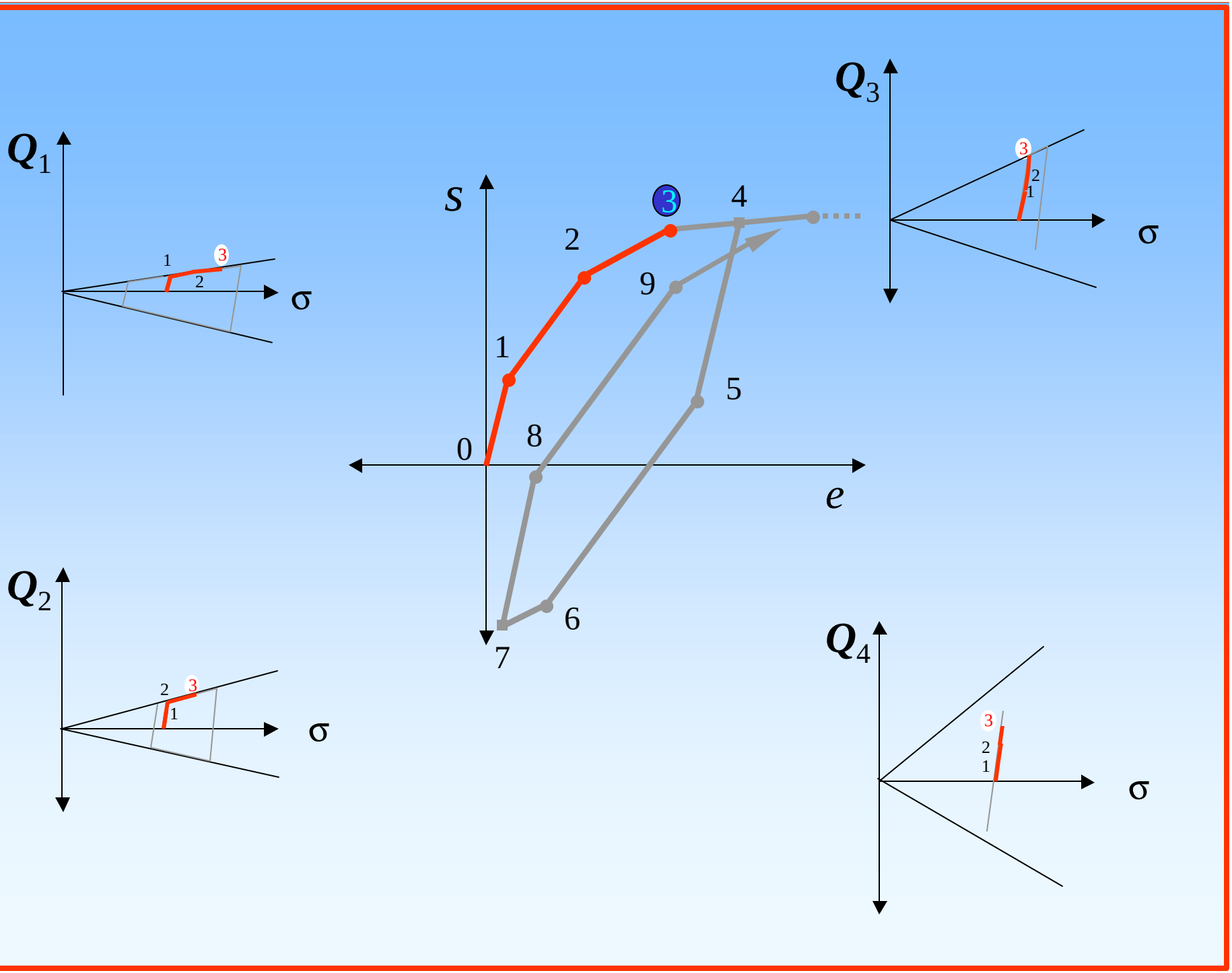
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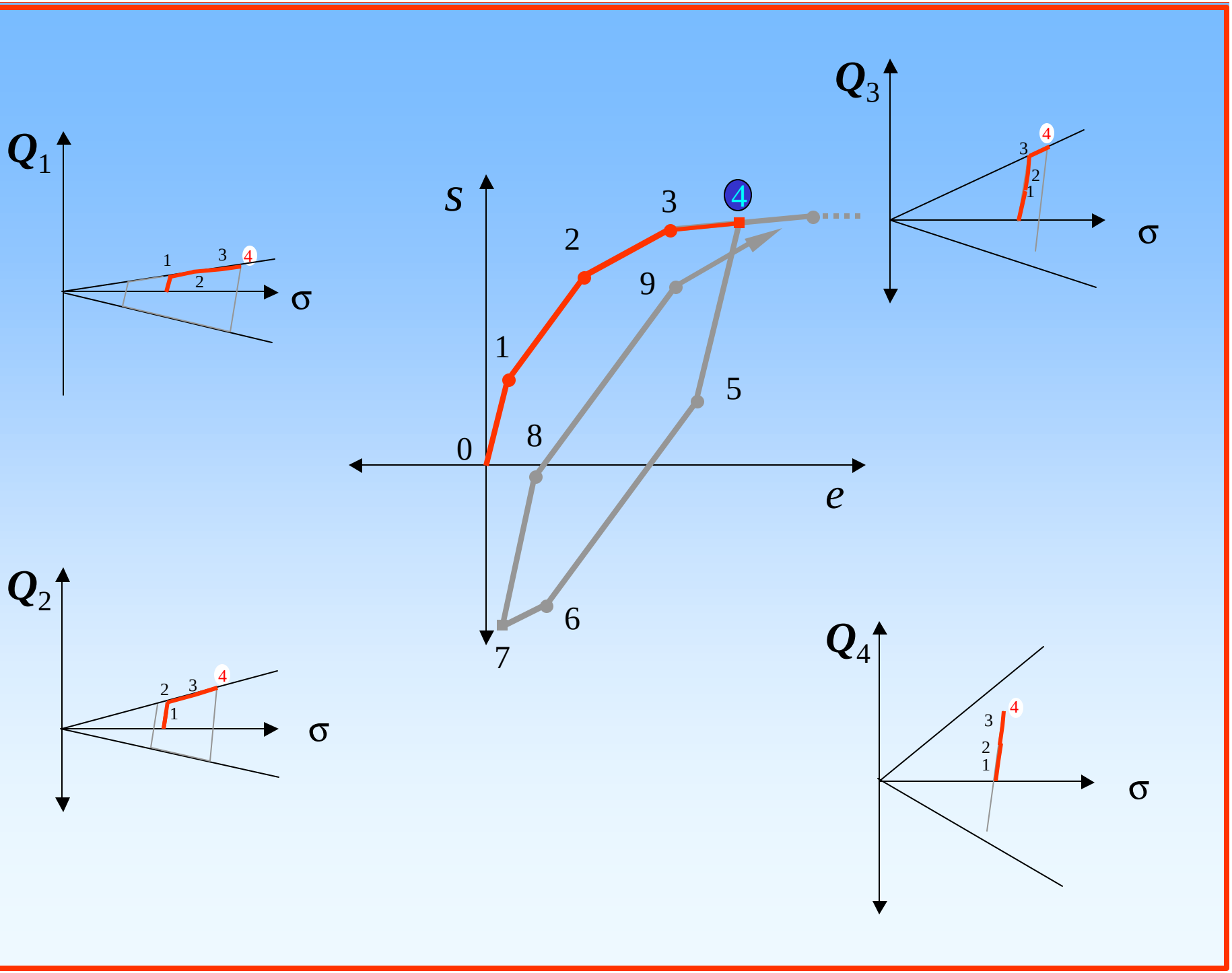
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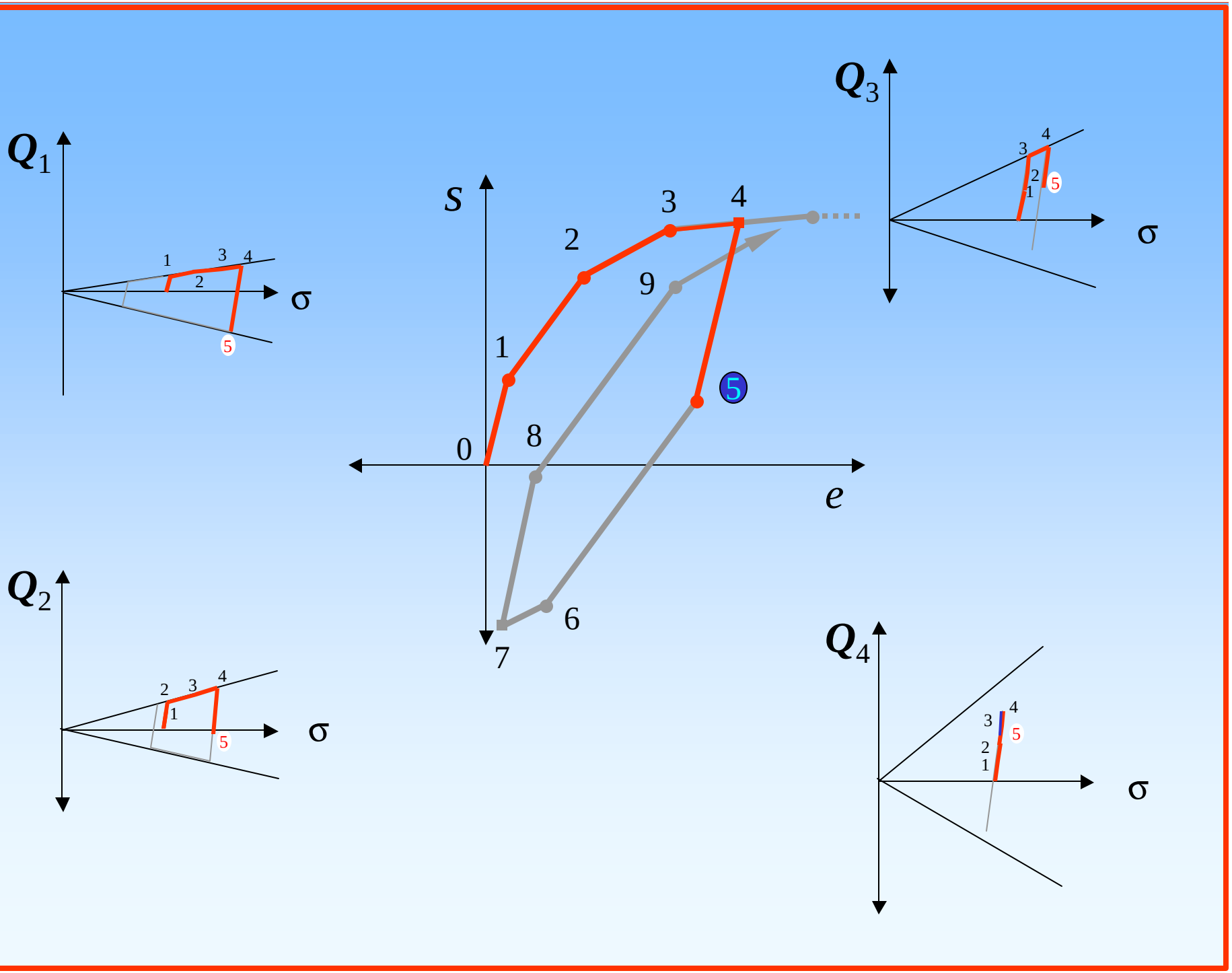
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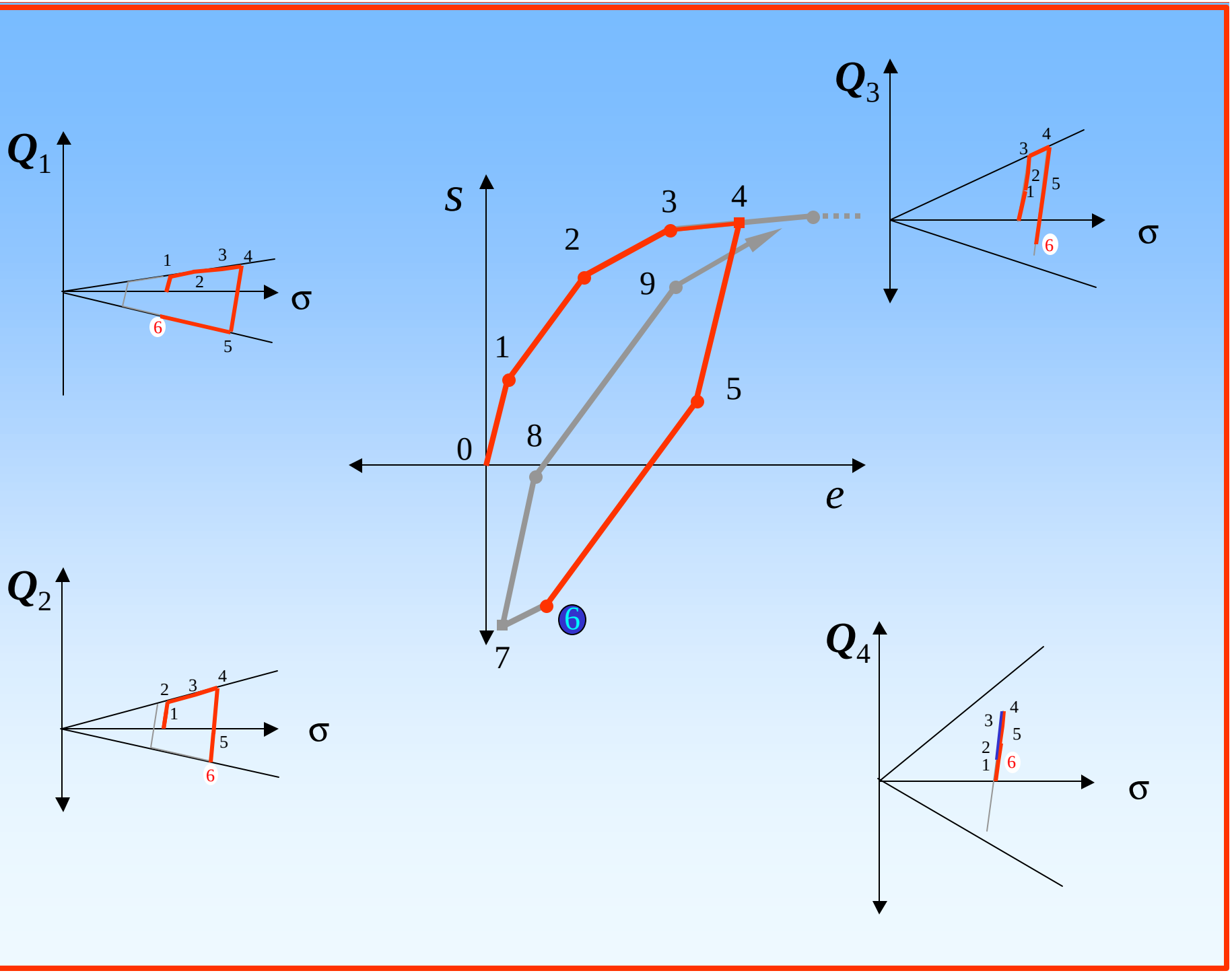
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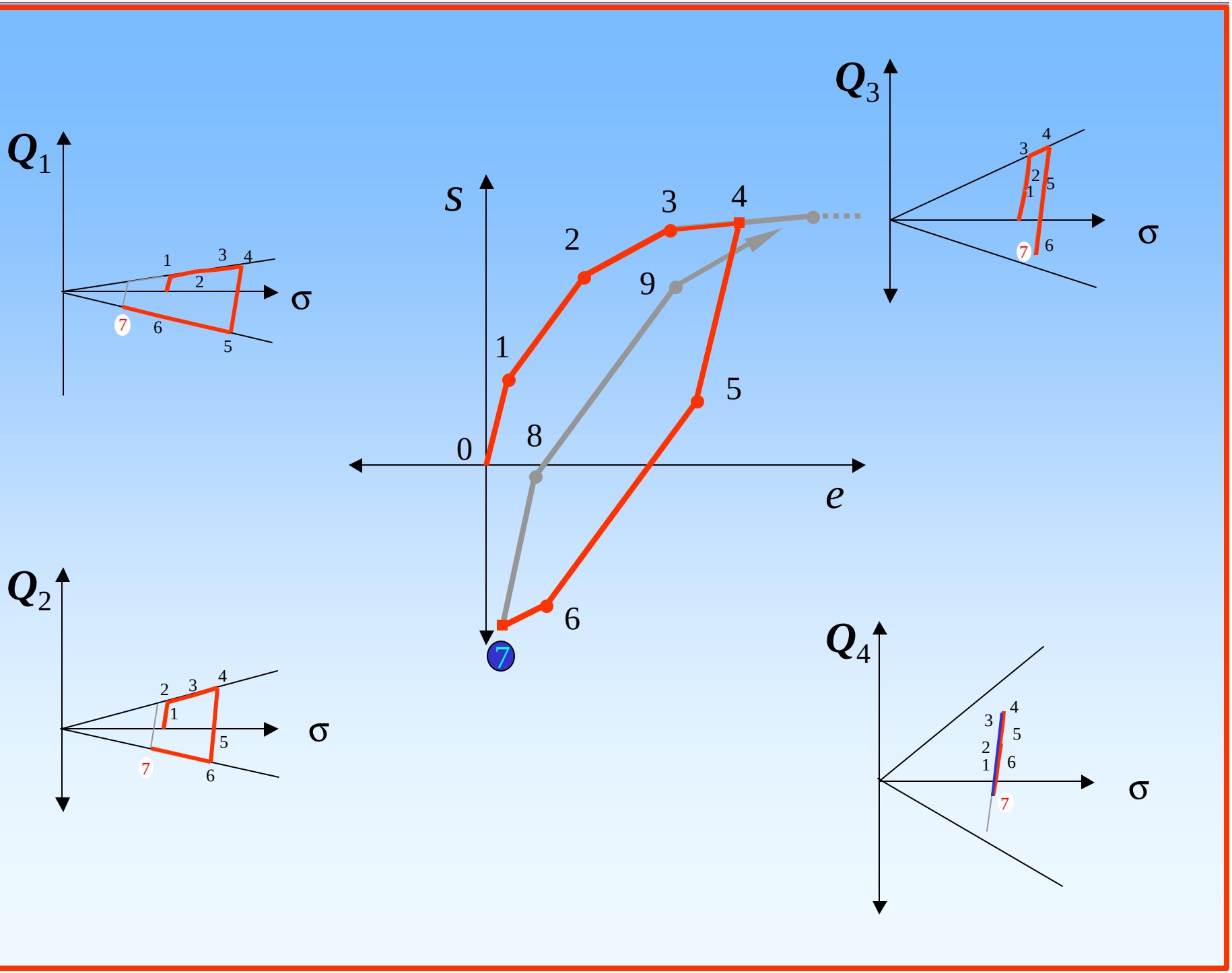
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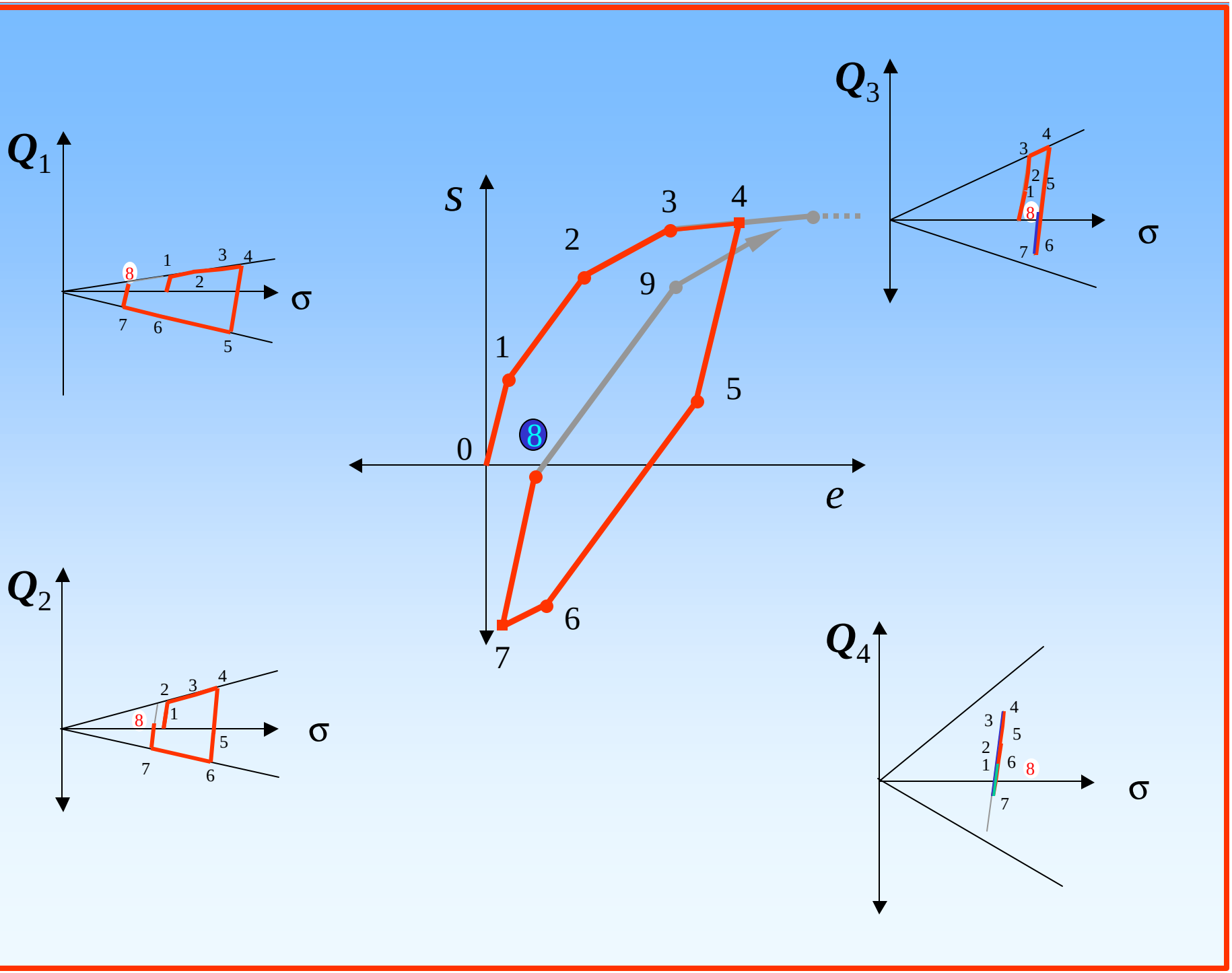
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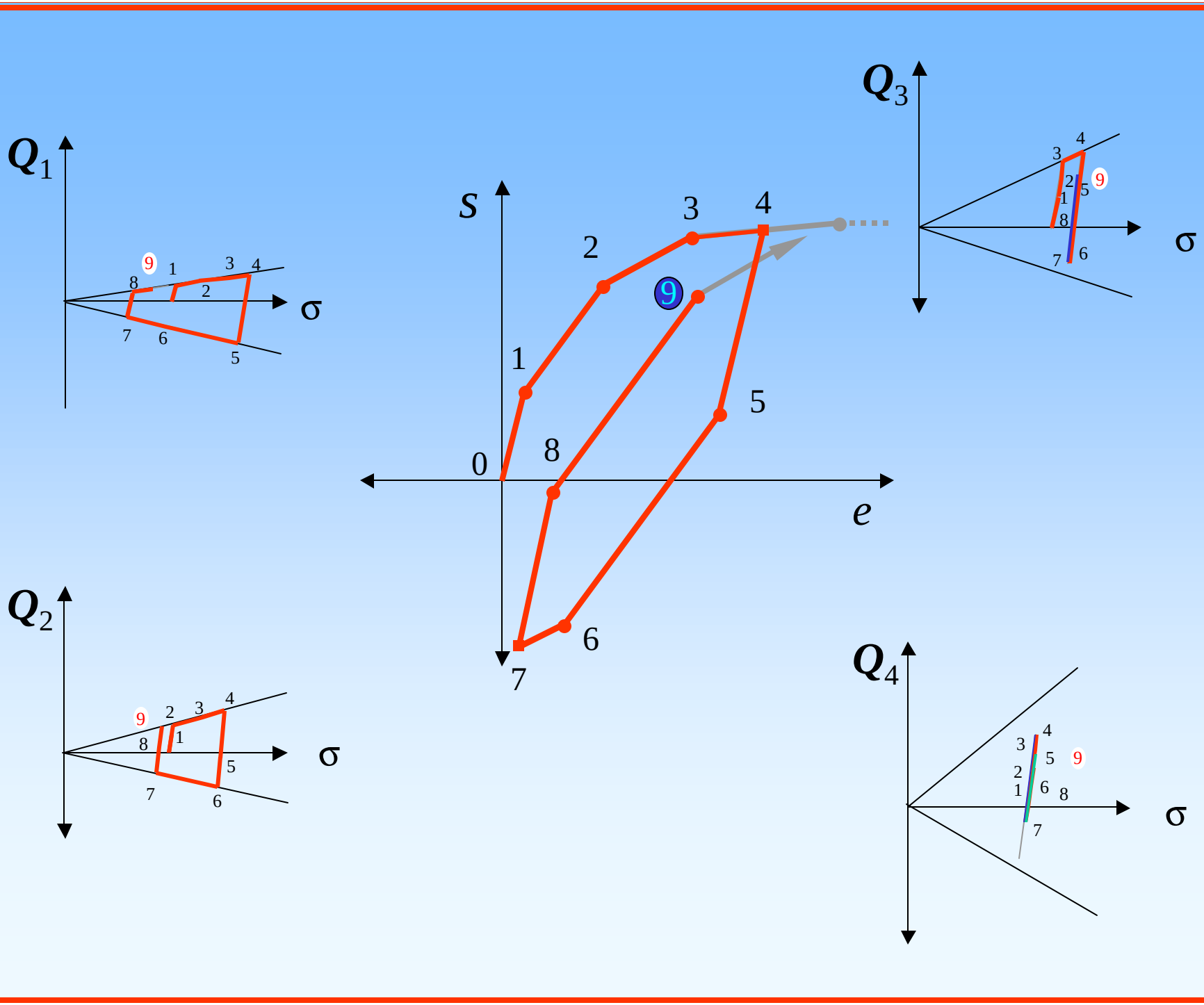
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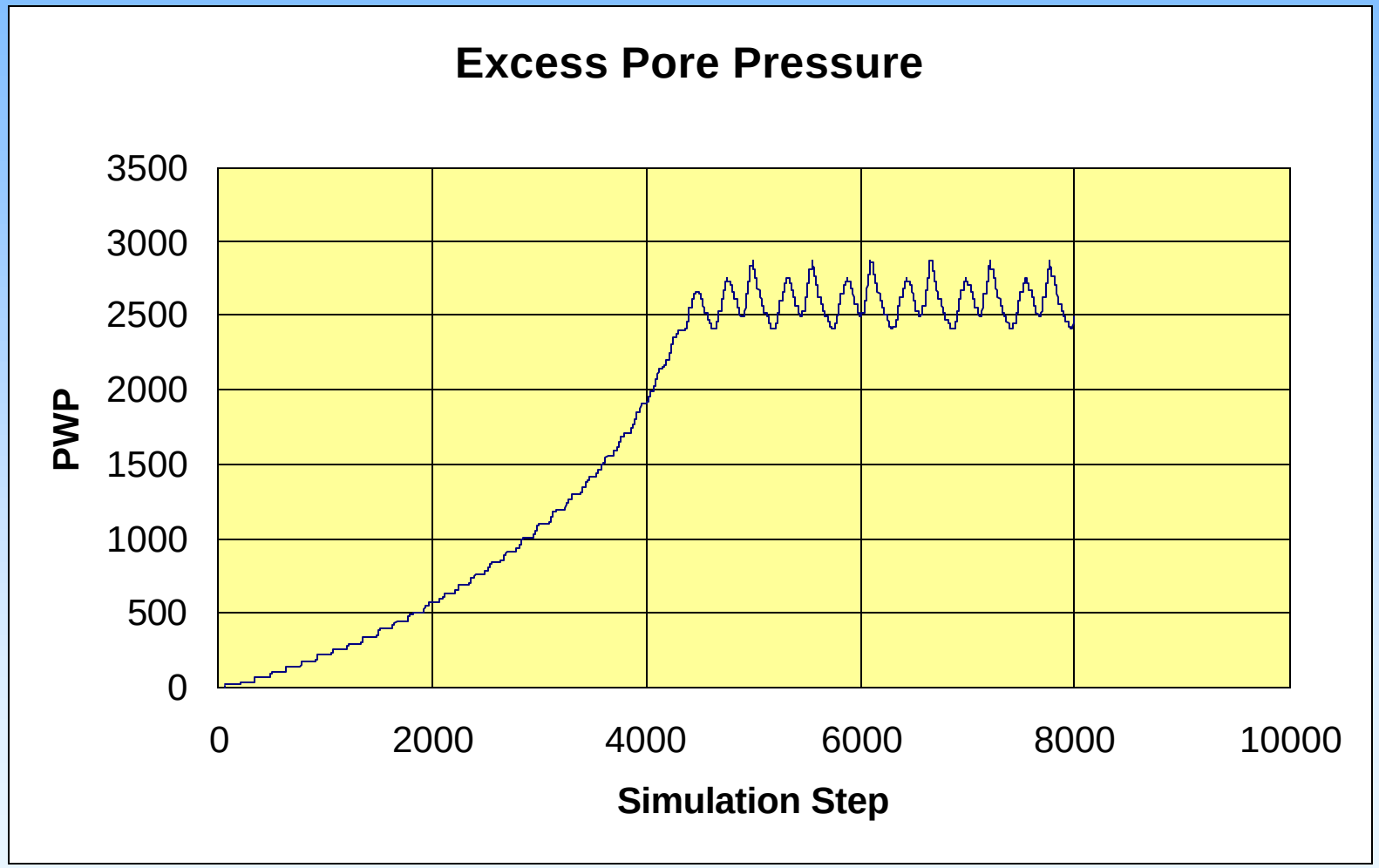
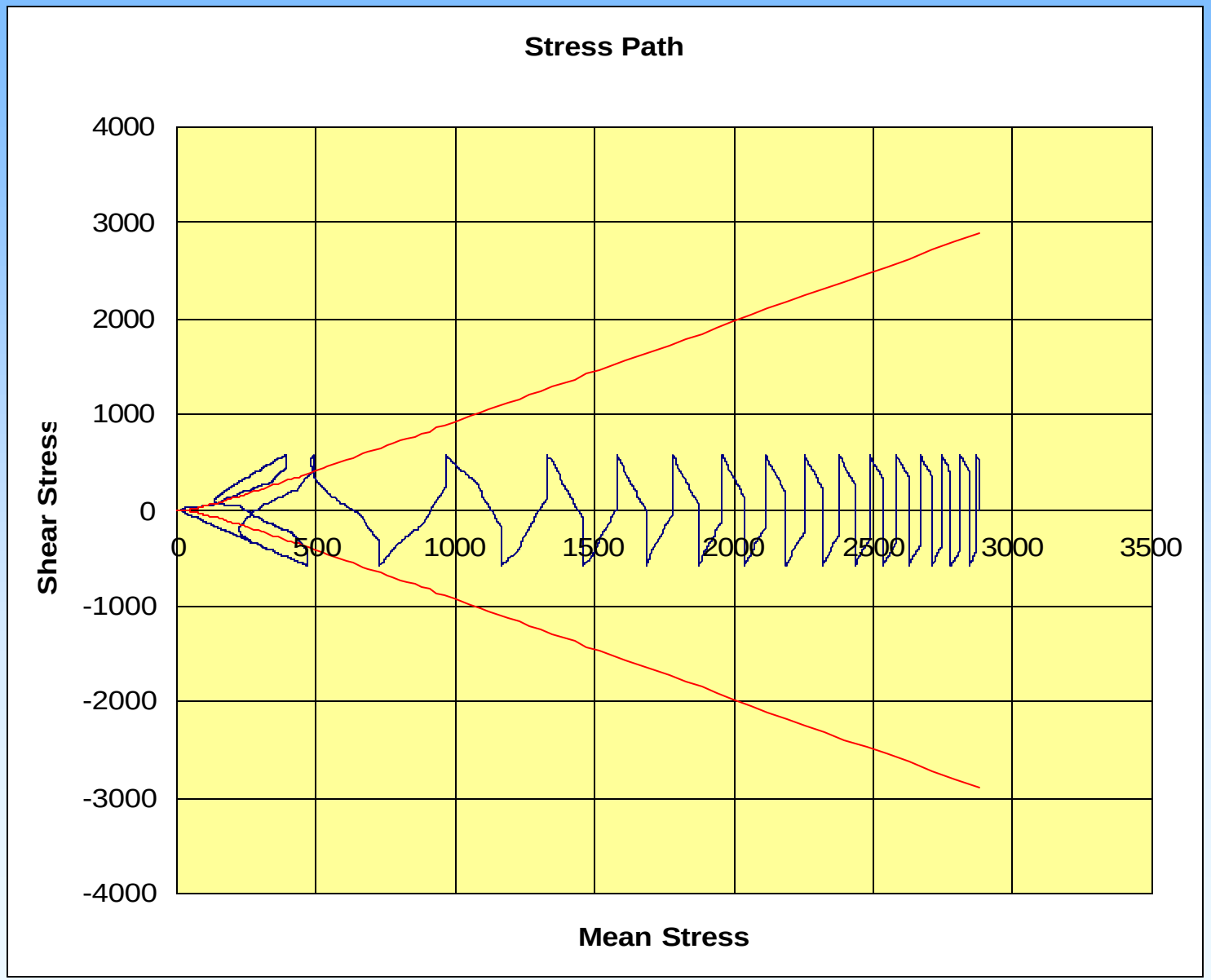
Pore Pressure Response



Stress Path


Stress Path
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Shear Stress
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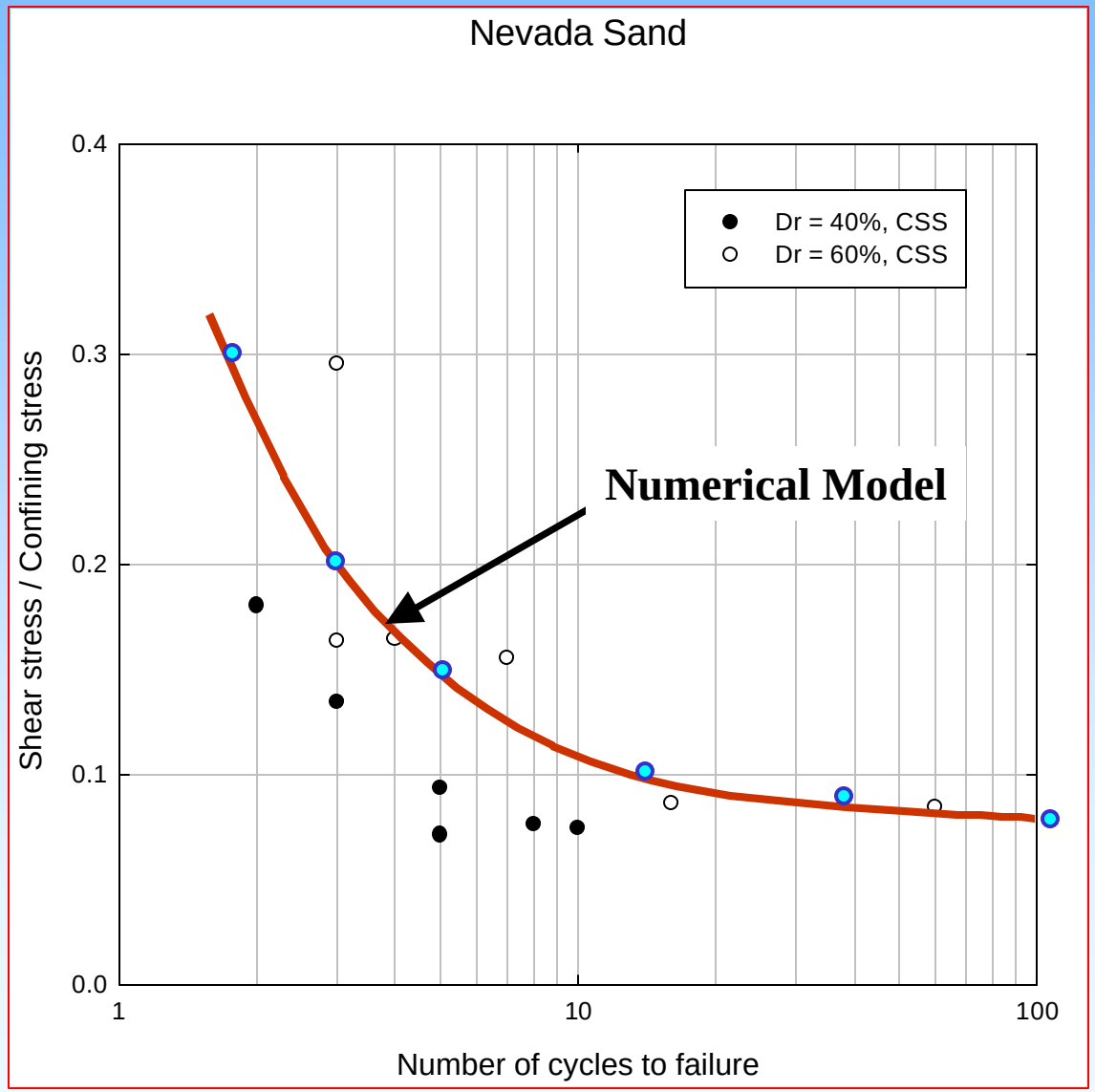
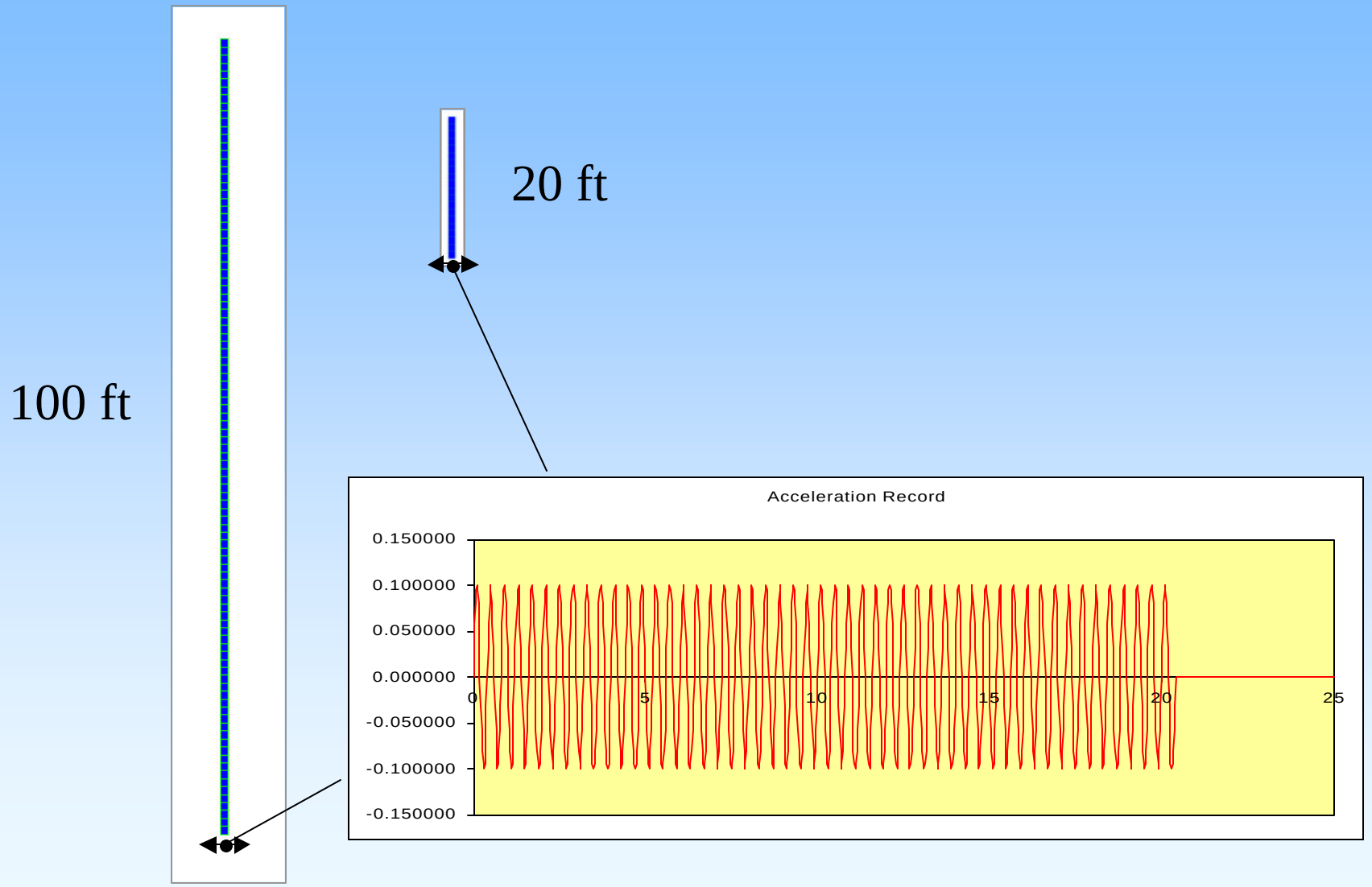
2500
3000
3500
Mean Stress

Cycles to Liquefaction

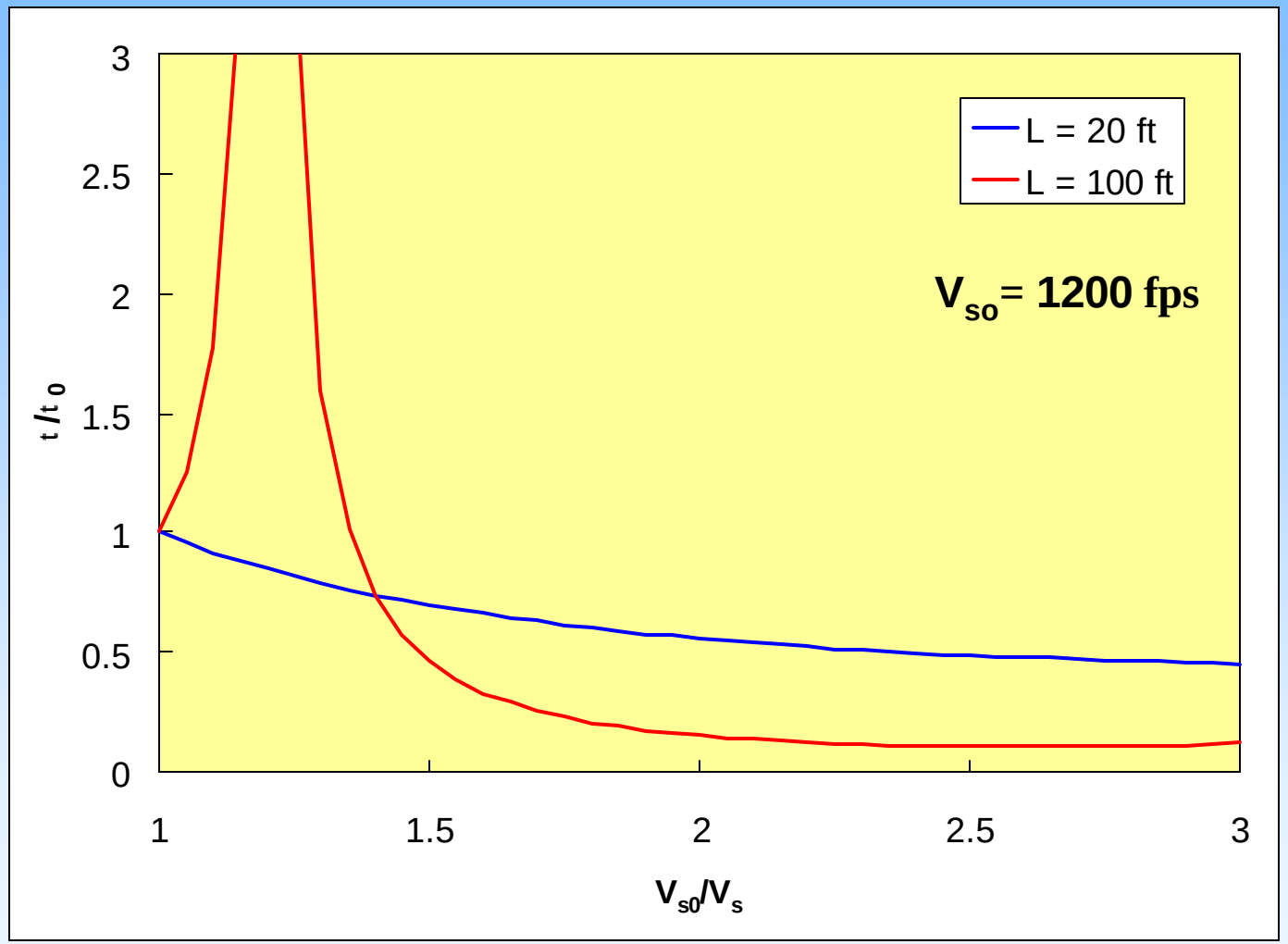


System Response

ANALYSIS OF A SAND LAYER

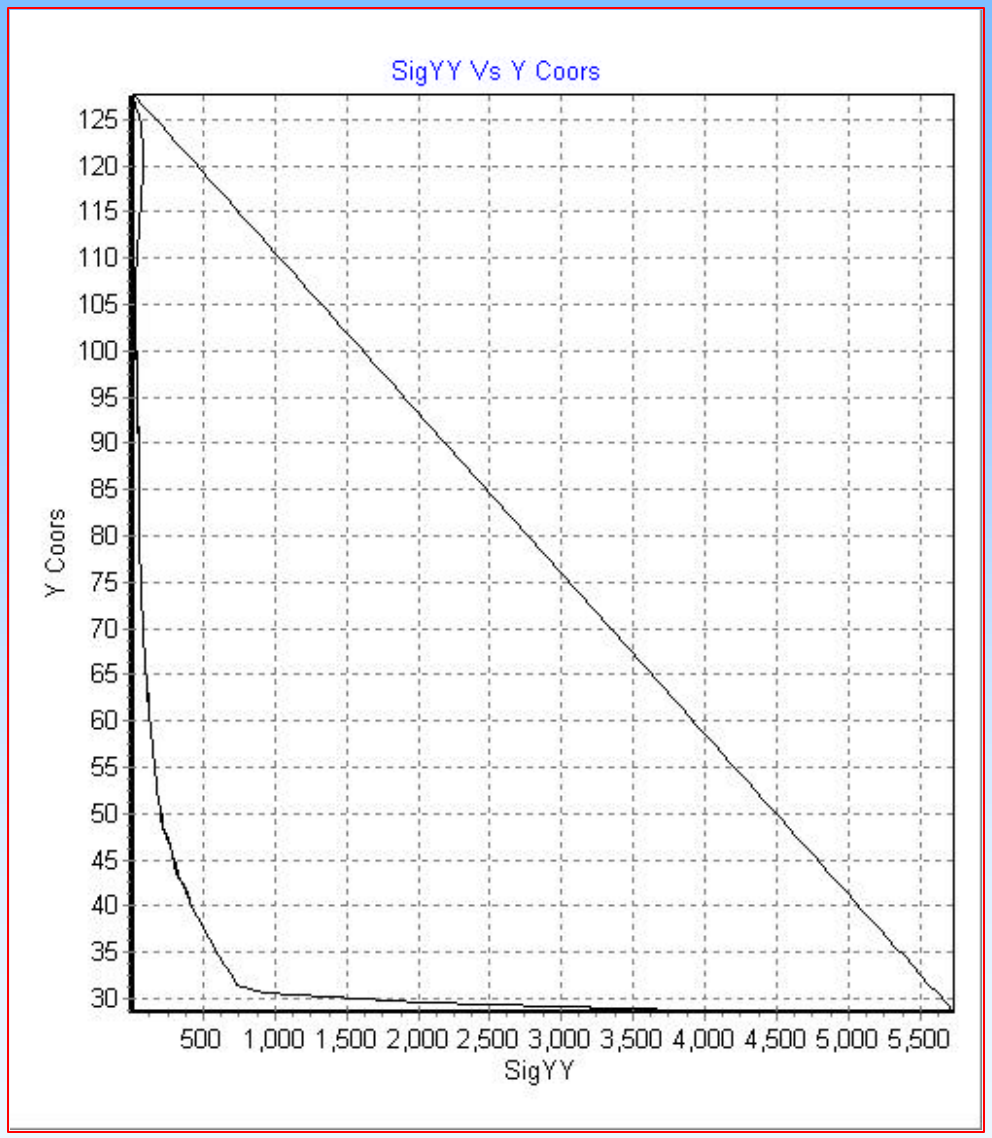


Comments on Linear-Elastic Response



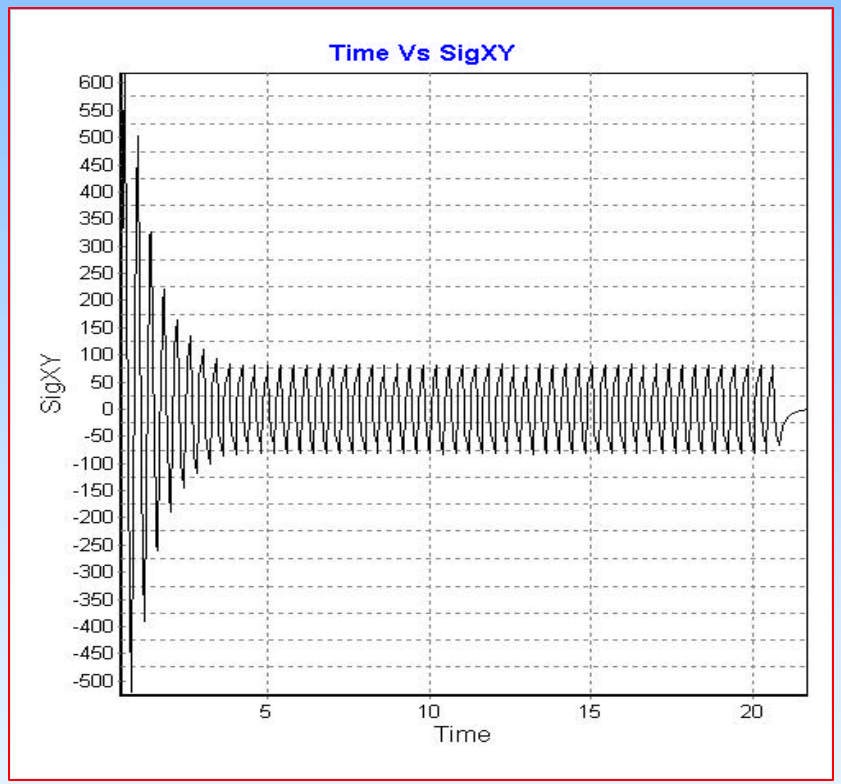
Decreasing Shear Wave Velocity

Effective Stress Distribution

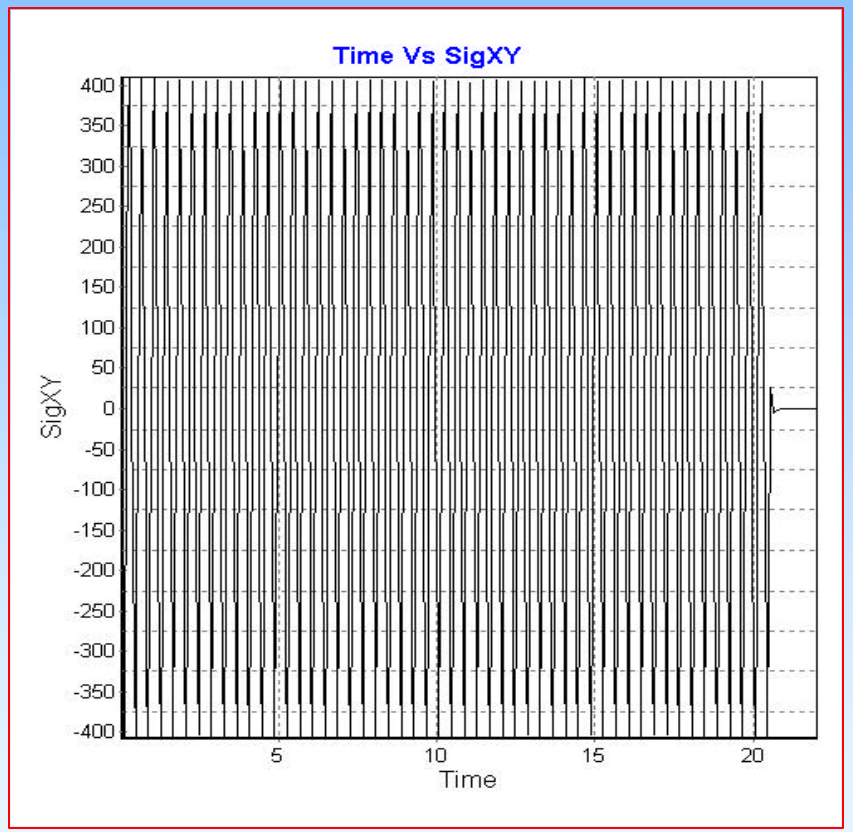


100 ft Layer

Shear Stress History

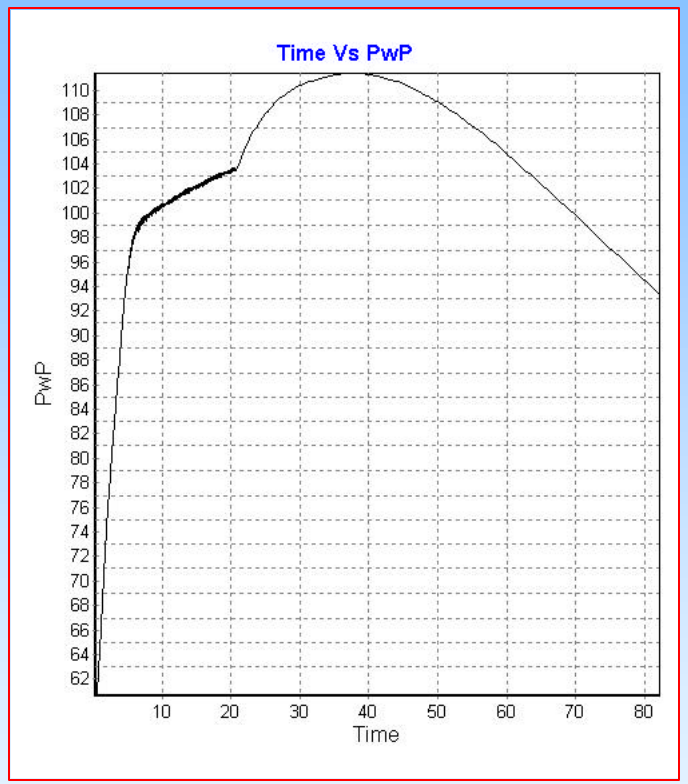


100 ft

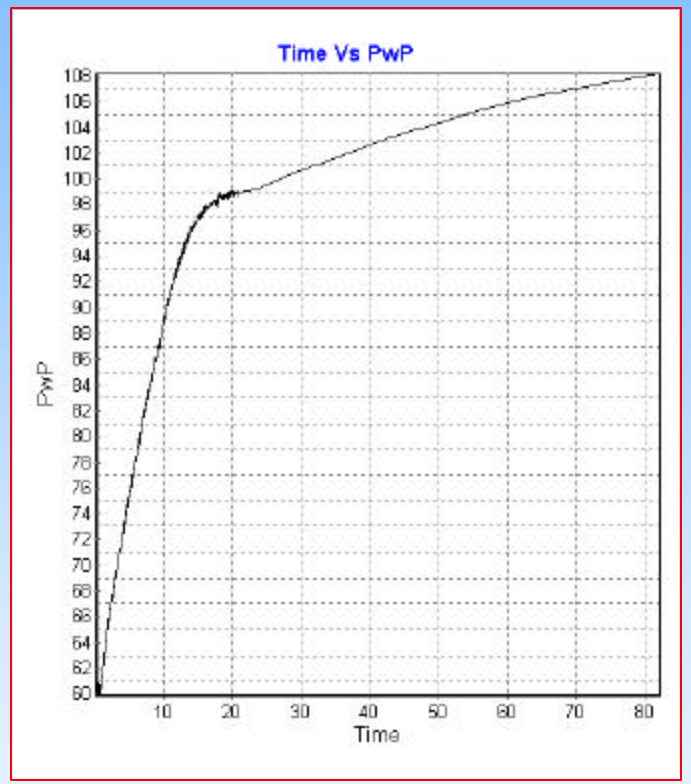


20 ft

Pore Pressure History at Top of 100 ft Layer



High Permeability



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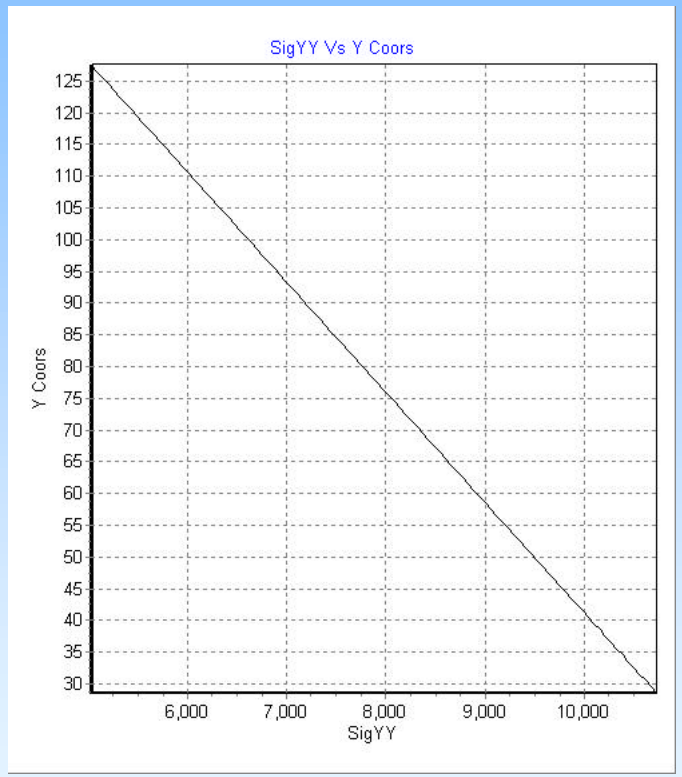
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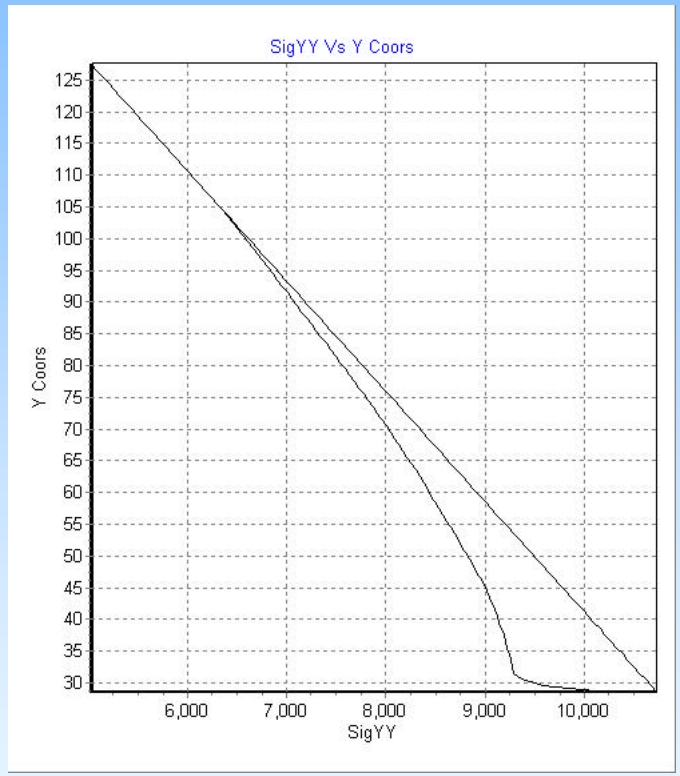
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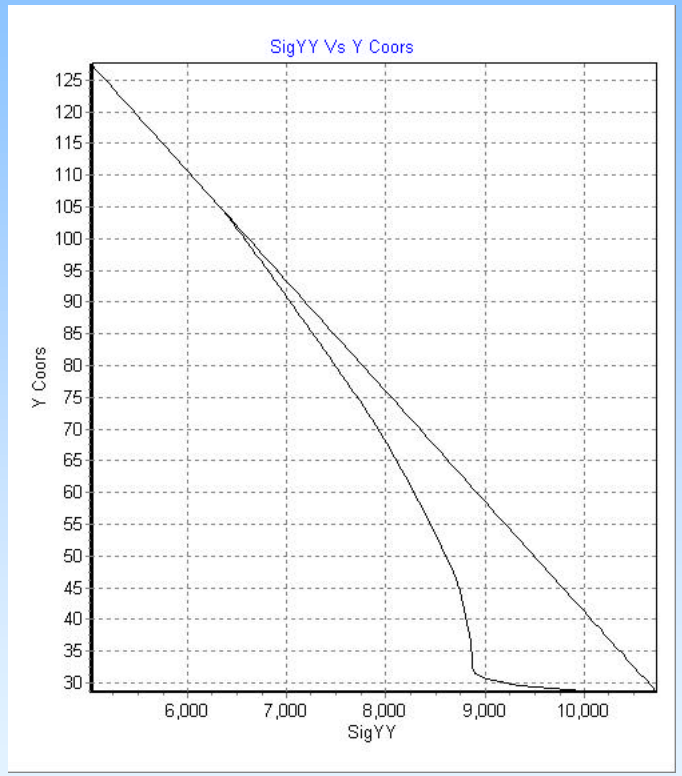
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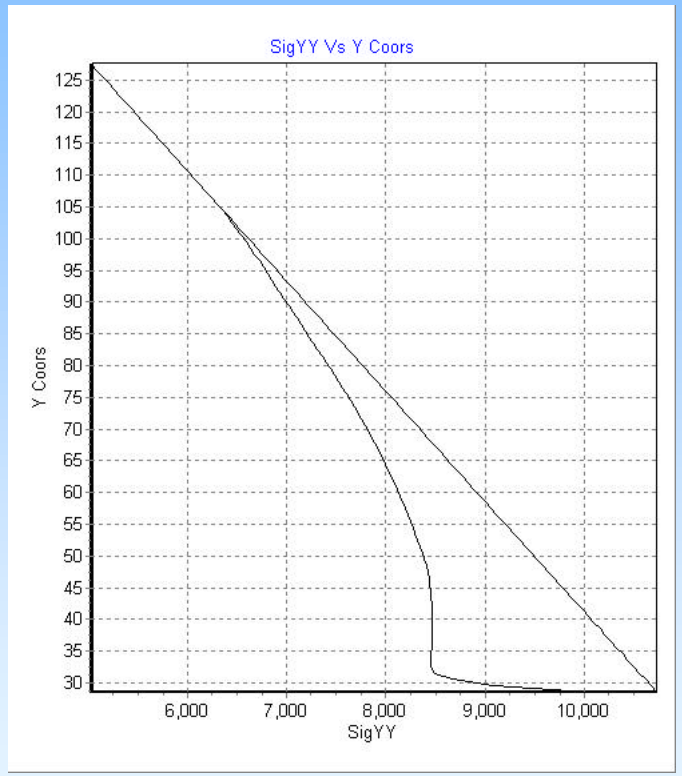
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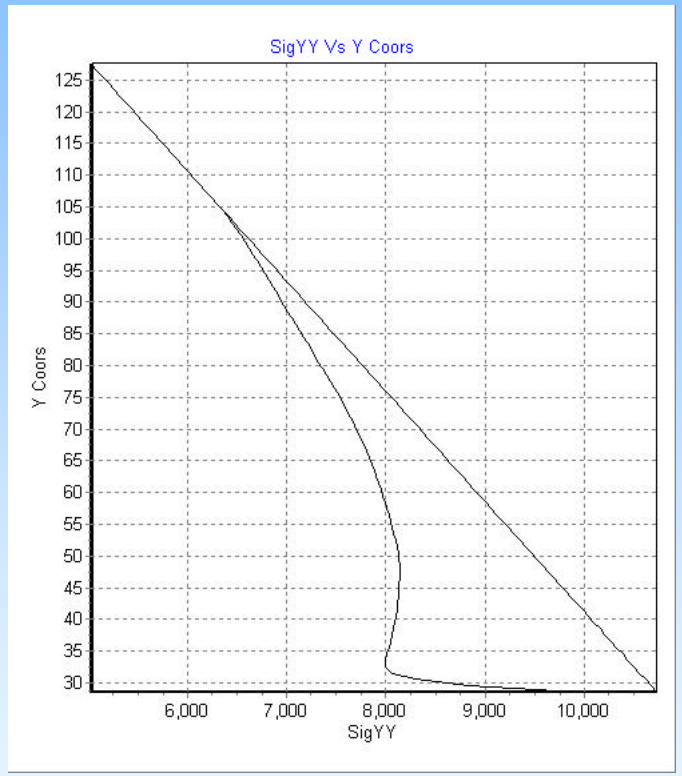
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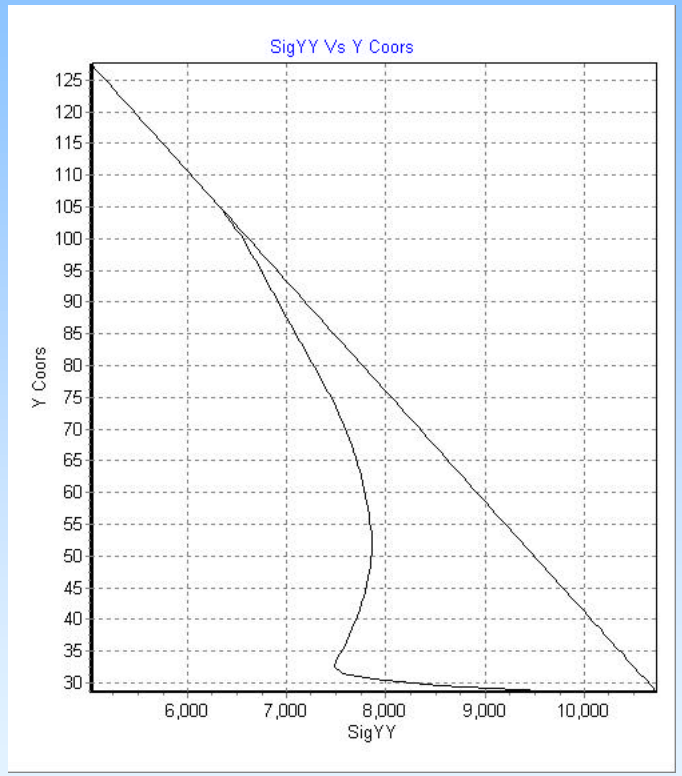
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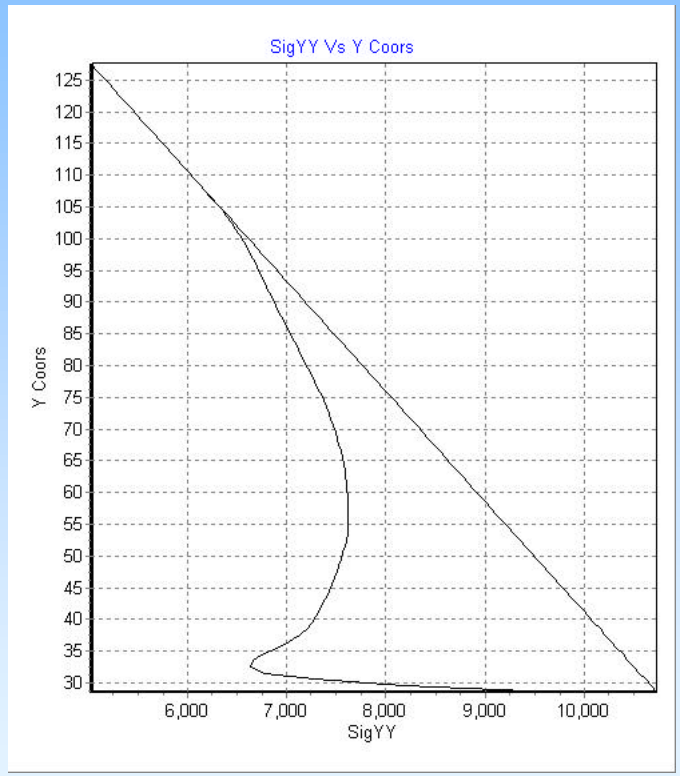
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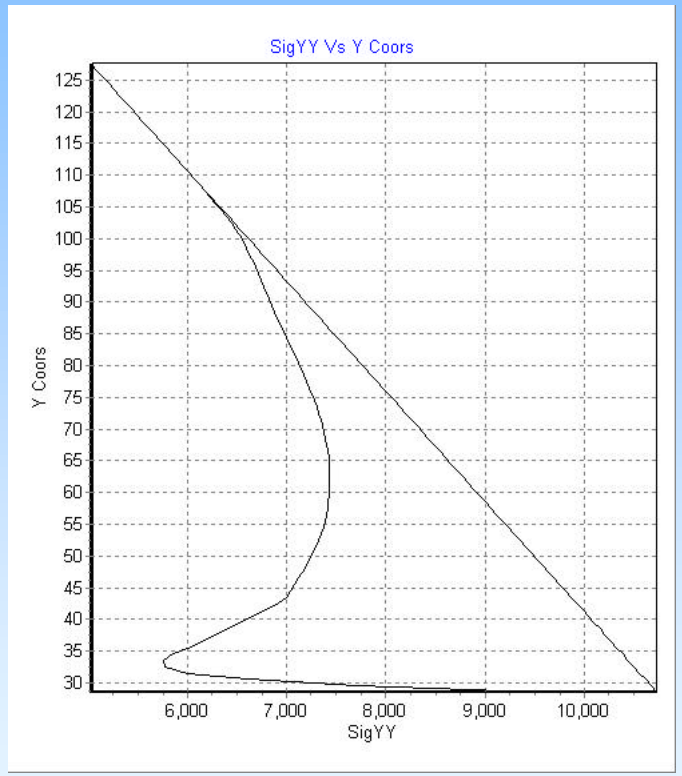
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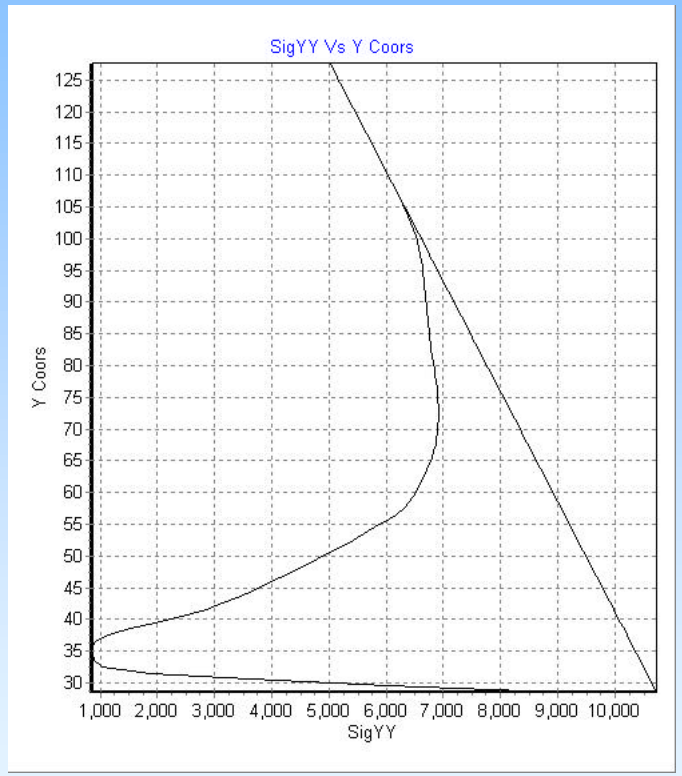
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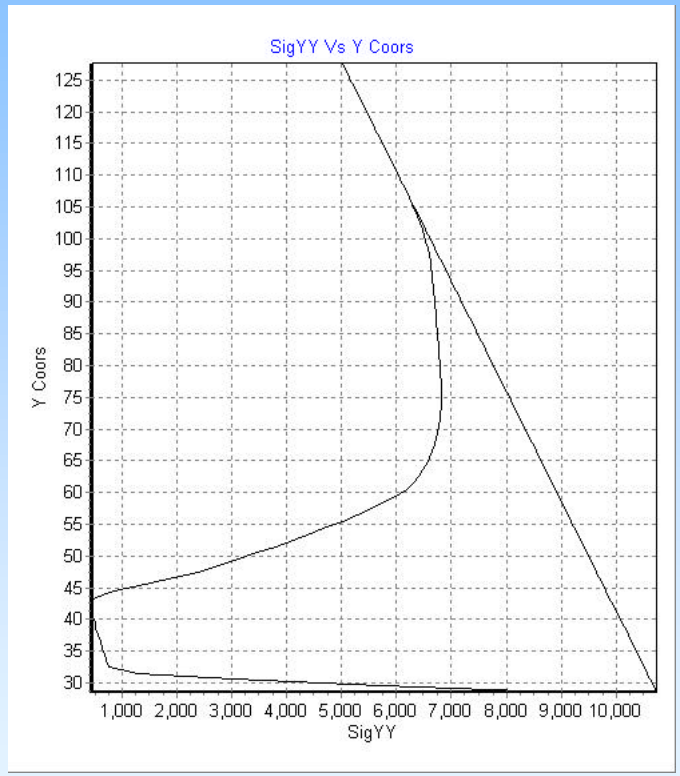
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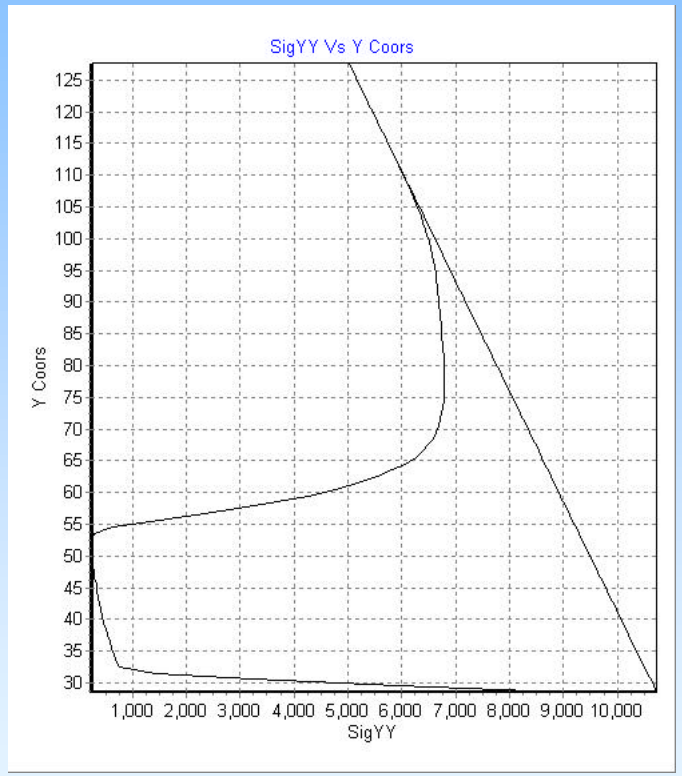
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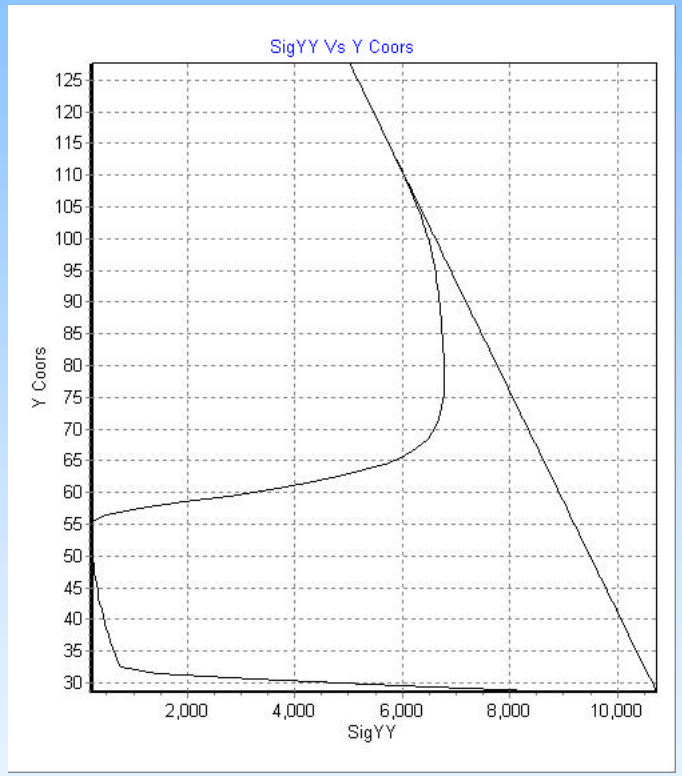
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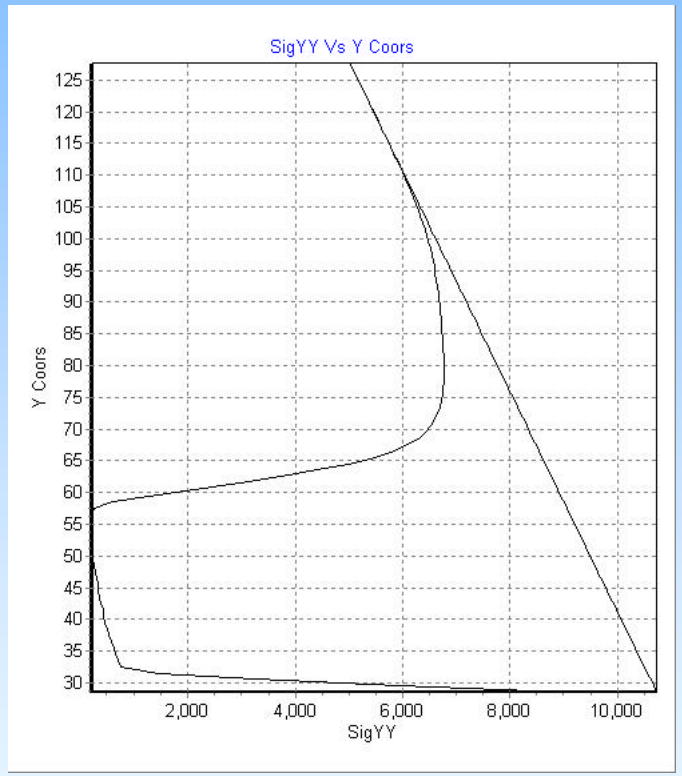
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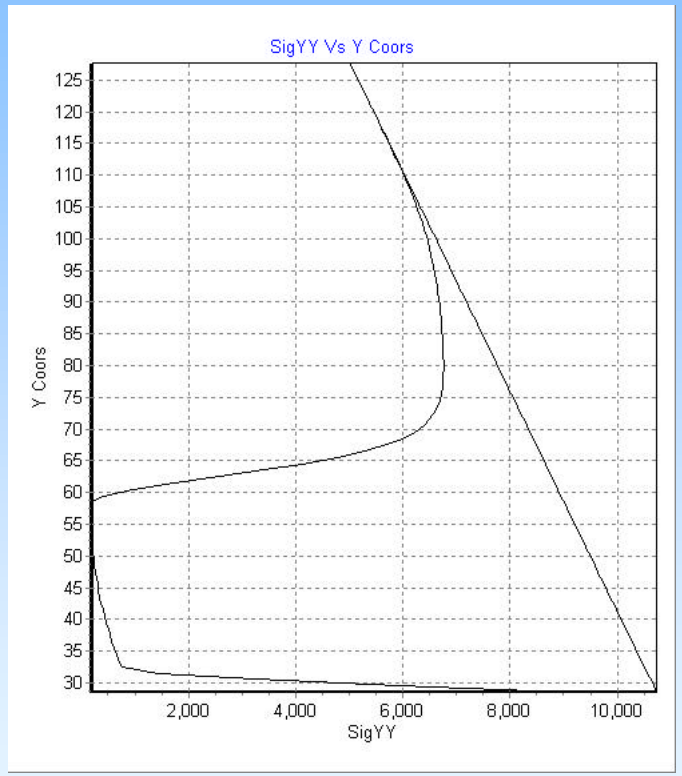
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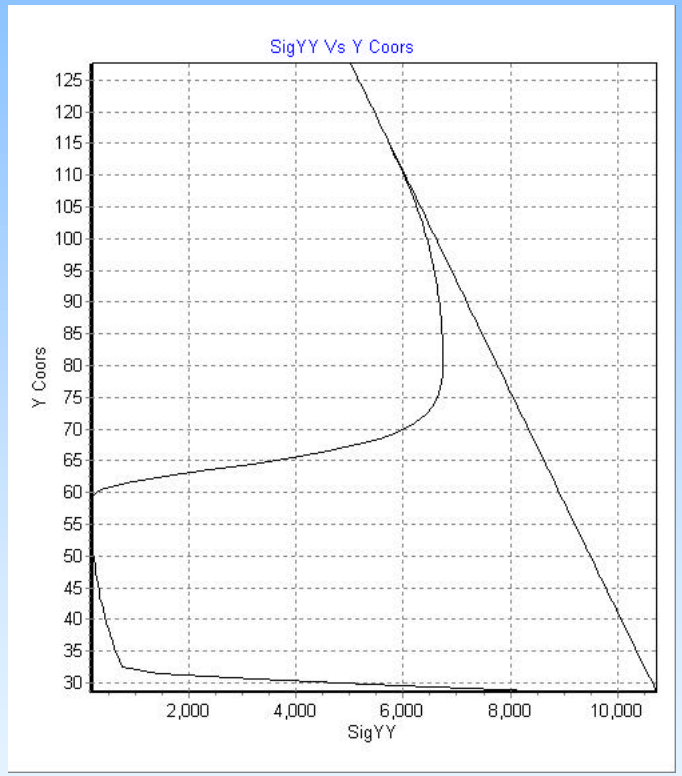
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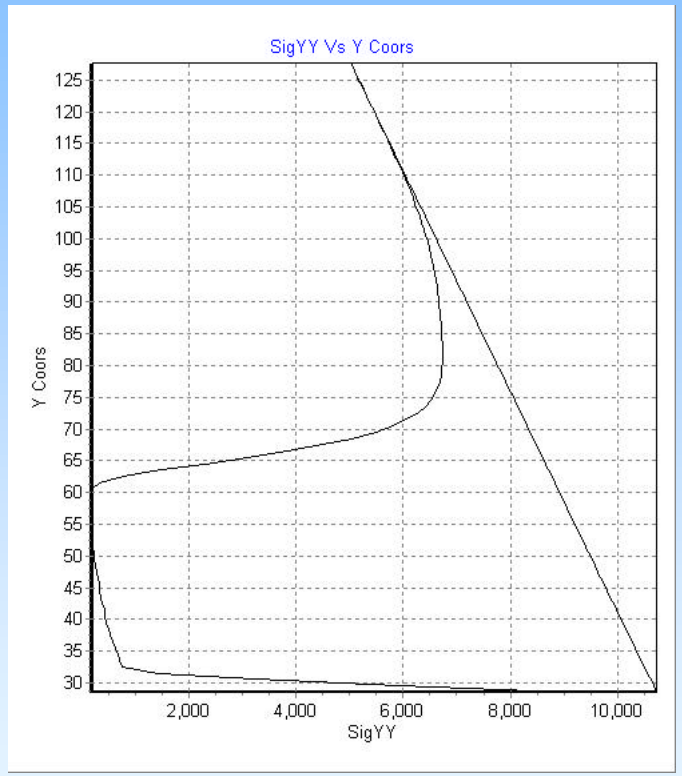
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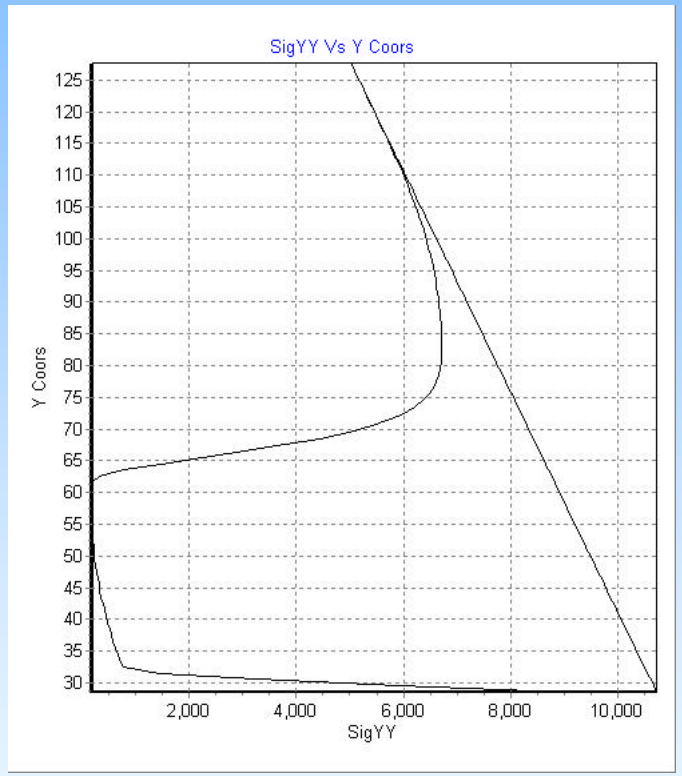
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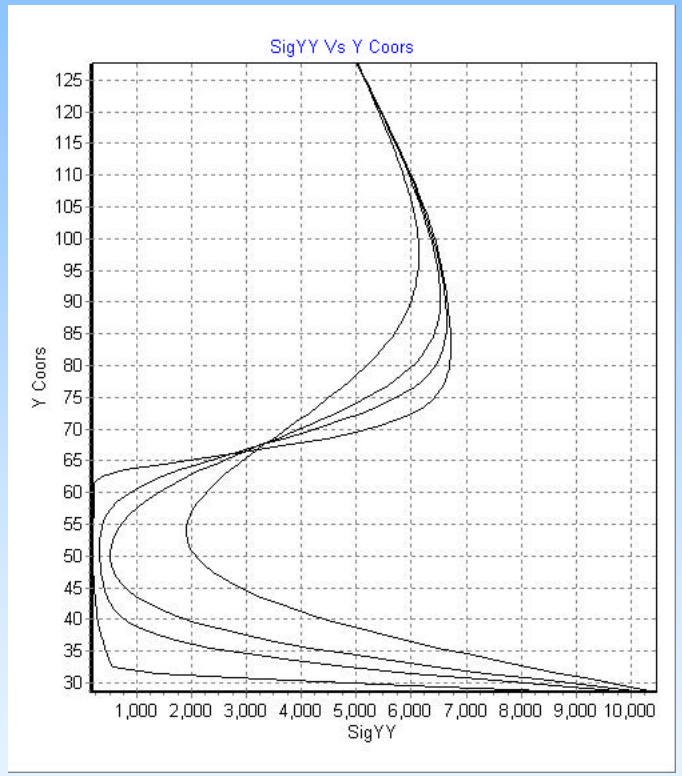
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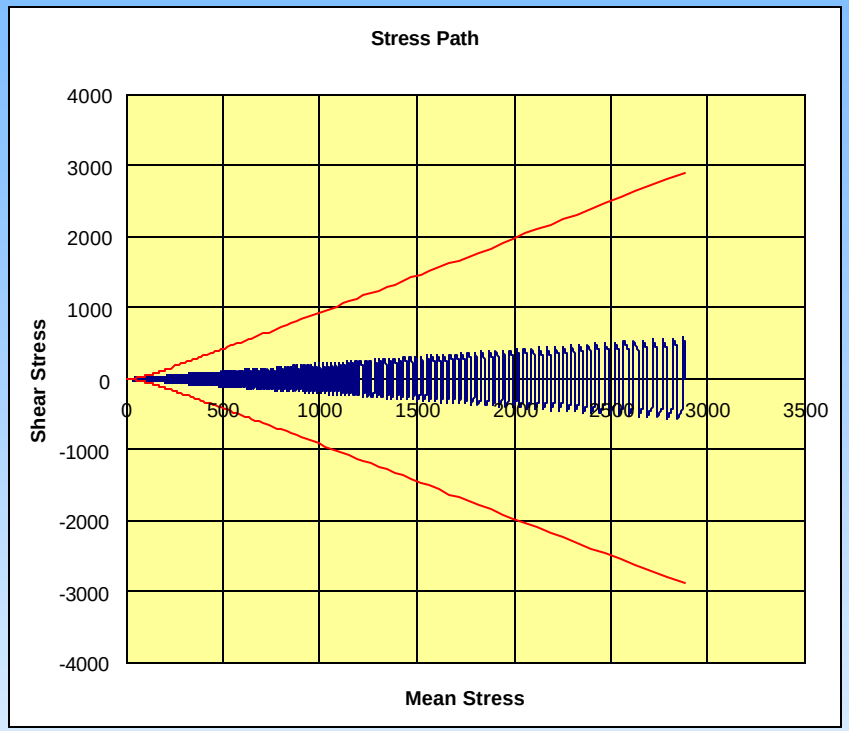
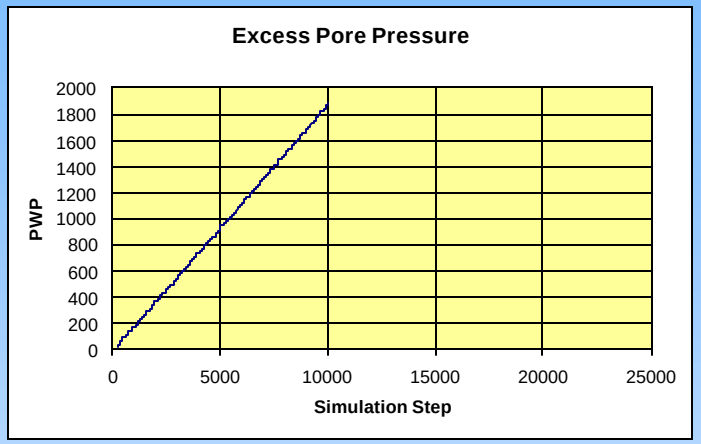
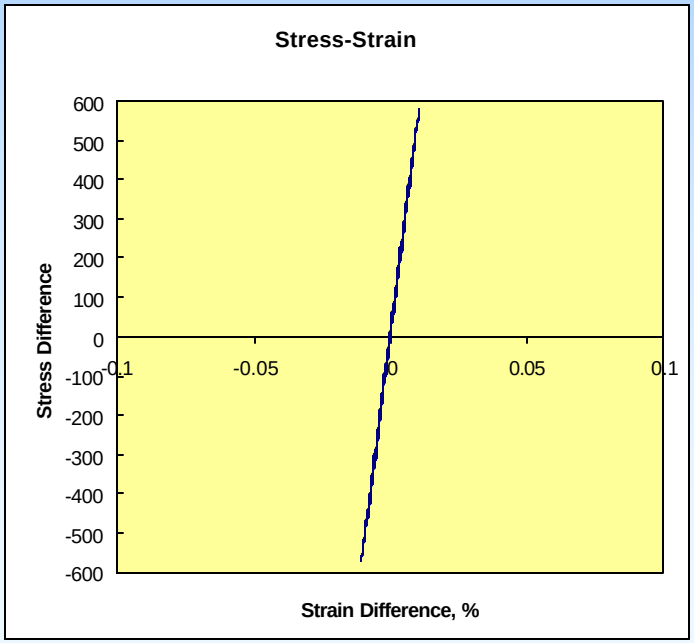
T > 20.0

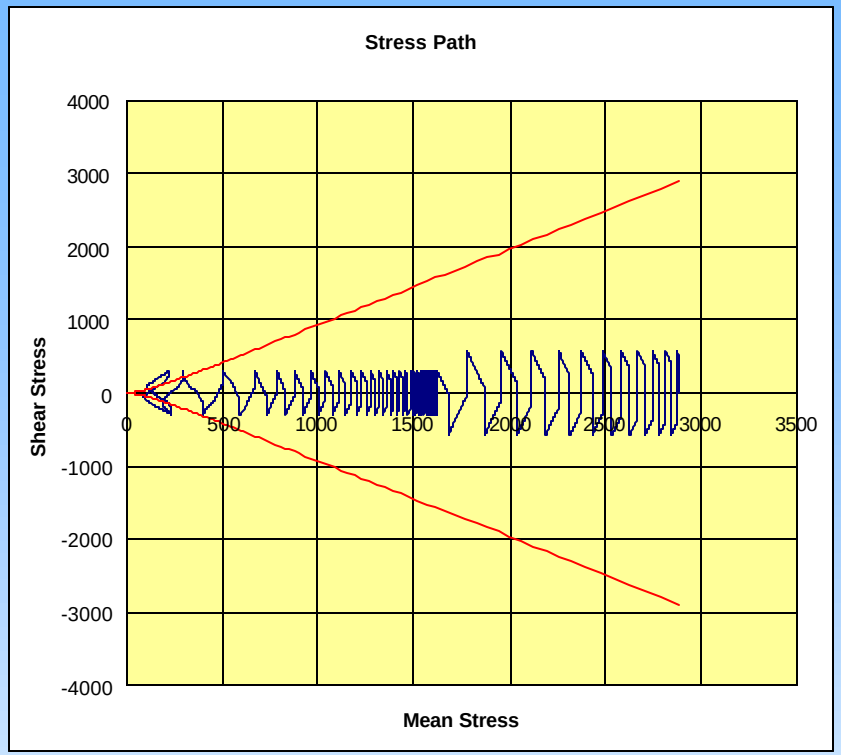
COMMENT ON ELEMENT RESPONSE

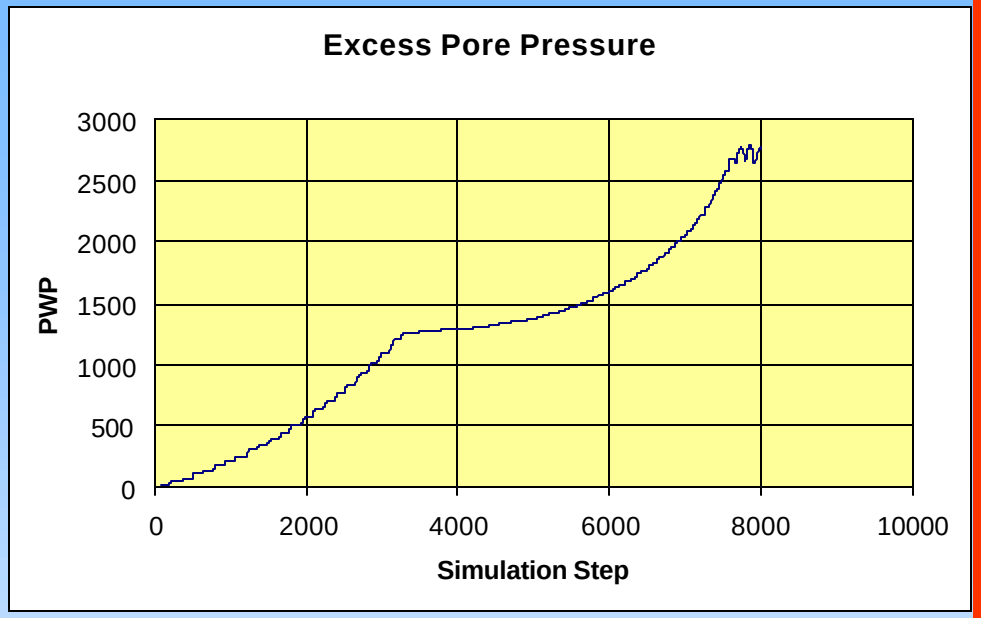




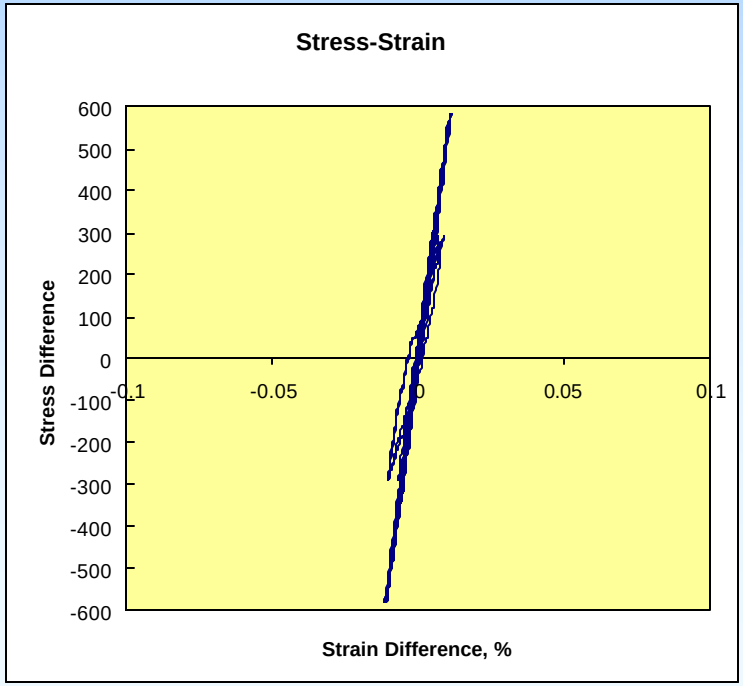


- Stress ratio a constant
- Continuous buildup in pore pressure
- “Stable” stress-strain response





- Reduced shear stress
- Reduced rate of pore pressure increase
- Eventual liquefaction but after many cycles



CONCLUSIONS

- ***Centrifuge results do not necessarily contradict "element" tests or previous experience gained for shallow deposits***

- ***Understanding liquefaction requires understanding foundation as a mechanical system.***

- ***Both dynamic response and consolidation effects tend to make liquefaction a shallow-depth phenomenon, although evidence is too thin to generalize results in terms of a depth cut-off***

Requirements for Additional Study

- ***Review formulation to determine need for including inertial effects in pore water (to explain strong linkage between deep and shallow layers).***

- ***More detailed analysis of development of instability***

- ***Consider effect of heterogeneity in foundation***

- ***Consider effect of embankment or berm***

- ***Consideration of more realistic base motions (non-uniform with both horizontal and vertical components)***

End of Presentation